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THE CONTRIBUTION OF INDUSTRIAL MELANISM IN THE LEPIDOPTERA TO OUR KNOWLEDGE OF EVOLUTION[1]

by

DR. H. B. D. KETTLEWELL

IT IS probably true to say that polymorphism, wherever found, offers a challenge to research. Longstanding polymorphism in a species implies a balanced state in which each genotype, occurring at a frequency higher than mutation rate, offers certain advantages to the species as a whole under the conditions of a varying environment. Under disadvantageous conditions one of the genotypes may be eliminated, in which case it will continue to reappear from time to time by fresh mutation. The gene-complex as a whole may therefore be fitted to receive it by past experience. It is my contention that industrial melanism, due entirely to a recently changed environment, has come about by the exploitation of genes which have from time to time in the past conferred advantages under conditions very different from those they find today. No new law of nature is invoked in this theory, and what we are now witnessing in our lifetime is the application, in an extreme case, of natural selection working on an infinite gene-complex.

In this paper I want to demonstrate some of the possible advantages and disadvantages which beset the dark and the light forms of different species of moths in the present-day countryside of Britain. Before introducing some of the seventy species of Macro-lepidoptera which are at present in the process of replacing their populations from light to black in industrial areas and far beyond, it is necessary for us to reflect briefly on the changes which have occurred in the British Isles in the past 10,000 years.

Following the last Ice Age, Britain had large areas of pine forest, and most trees, boughs and rocks were covered with a heavy coating of lichens. Since then the indigenous pines have been succeeded by deciduous trees, so that pines became extinct in all except the northern parts of the island. More recently the countryside was broken up into a series of isolated woodlands due to the system of enclosures which took place about the middle of the eighteenth century. Still later, following the Industrial Revolution, large areas of Britain have been overrun by factories and townships. These industrial areas can be referred to on the map under the following six districts: Glasgow, Newcastle, Lancashire and Yorkshire, Midlands, South Wales and Bristol, and London. Due to the prevailing south-westerly winds, smoke from these areas drifts to the east and less frequently to the west. To emphasise the importance of air pollution, it must be stated that immediately around the industrial areas air pollution is measured in tons per square mile per month, and that this may reach a figure of fifty tons per square mile per month on frequent occasions. Further afield, in supposedly rural areas, the lighter portion, in the form of 'smoke', which according to Dr. E. T. Wilkins may drift a thousand miles, is measured in milligrammes per cubic metre of air. Its profound effect on the natural history of England over a period of years has been overlooked. Apart from gross foliage damage which occurs immediately around industrial areas, the following changes may be attributed to it: lichens, which appear to be peculiarly sensitive to its effects, rapidly disappear, and Dr. Eustace Jones has shown that both

[1] Précis of paper read to Sections D (Zoology) and K (Botany), in the author's absence, on September 3, 1956, at the Sheffield Meeting of the British Association.

the number of species present and the total lichen population is reduced directly proportional to the proximity to an industrial centre. The tree-trunks eventually become naked and black, but further away this may be confined to the undersides of boughs and the 'rain-runs' down the tree-trunks. Leaves are covered with a precipitation of soot, and these same leaves are the food of most lepidopterous larvae. There is diminished sunlight due to haze and 'smog'. These changes therefore affect not only the industrial areas themselves, but far beyond them, for the most part to the east.

It is probable that the Lepidoptera reflect the effects of these changes in a most sensitive way, and I wish now, by way of introduction, to refer to a few of the species exhibiting melanism. In Plates I and II, in each case the original light-coloured form is shown on top and its melanic beneath. It will be noted that the light forms frequently have complicated wing patterns with the object of enabling them to pass the daytime at rest on lichened boughs, trees or rocks.

PLATE I. *Right*, 1 and 2: *Tethea ocularis*. This is probably the only example we have in Britain of where, instead of a melanic mutation, the black form was introduced by migration from the Continent. Prior to 1947, whilst the melanic *ocularis* was well known in Holland, only one record was made in this country. Since this date, when numbers of melanics were taken throughout Eastern Britain, the proportion of melanic to typical has gone ahead, so that in recent years the figure for the Cambridge district is over 50 per cent black in a sample of approximately fifty.

Right, 3 and 4: *Tethea or*. About 1907 the first melanic *or* was taken near the industrial city of Hamburg, North Germany. By 1917 a sample of wild larvae gave the figure as over 90 per cent of the black form. In England the black form has not been recorded from authentic specimens until recently, the mutation, presumably, not having taken place.

Right, 5 and 6: *Tethea duplaris*. In the North of England and parts of Scotland this third member of the genus *Tethea* is dark. More recently in most industrial areas the black form has taken over up to approximately 90 per cent of the population.

Right, 7 and 8: *Apatele alni*. In the Sheffield district about 80 per cent are now of the black form.

Left, 1 and 2: *Stauropus fagi*. The melanic form has now superseded the typical around the whole of the London area commencing in Epping Forest.

Left, 3 and 4: *Polia nebulosa*. In the majority of species the black form is inherited as a simple Mendelian dominant. In *nebulosa* the heterozygotes are intermediate and recognisable. In this case selection may have favoured the heterozygote because in spite of extreme blackness in the homozygote the fringes of the wings are white and the insect is conspicuous at rest.

Left, 5 and 6: *Dasychira pudibunda*. The melanic form has only occurred in the last fifteen years but is now replacing the typical in Surrey and elsewhere.

PLATE II shows further examples of industrial melanics. I will only remark on the following two species:

Left, 3 and 4: *Antitype chi*. This was the species on which Professor Heslop Harrison did daily counts of both forms at rest by day on the walls around Newcastle. In conclusion he stated that he but rarely noted a melanic specimen missing and that therefore he believed that bird predation played no part in the spread of industrial melanism. I hope in this paper to show you that this most certainly is not the case.

Left, 5 and 6: *Ectropis consonaria*. In North Germany the black form has replaced the light in industrial areas. In England the species has disappeared from many industrial districts, probably because the melanic mutation has not yet taken place there. The black form occurs, however, in two widely separated areas of

woodland, one in Kent near Maidstone, and another in Gloucestershire. We are at present breeding this species with the object of releasing known numbers of individuals of both forms into districts from which it has disappeared.

PLATE III, *Procus literosa*, is an example of where a species has disappeared from an industrial centre, Sheffield, and where it is now reappearing, but in its melanic form which is enabling it to regain lost territory.

I have stated that the inheritance of the melanic form is nearly always a unifactorial Mendelian dominant. This is not always so, however.

In *Lymantria monacha* the melanic form has spread through industrial Germany. The darkest individuals are the product of three genes, one of which is sex linked, and in each case dominant.

PLATE II. *Right*, 3 and 4: *Phigalia pedaria*. This has two separate melanics. One occurs in both sexes and is a simple dominant. It has spread through industrial areas. It also occurs at low frequency in the Highlands of Scotland. The second is sex limited to the female and is probably carried in the Y chromosome.

These, then, are examples of melanics which are at present spreading through the central and eastern counties of Britain.

We chose in the first place, for a full investigation, the species *Biston betularia*, which has two melanics, *carbonaria* (Jordan) and *insularia* (Th-Mieg). The first two are figured on Plate IV. Both melanics are dominant to the typical form and *insularia* is unable to be recognised in the presence of *carbonaria*. We have recently been able to show that the two forms are not alleles and are in fact situated at different loci.

Betularia has certain advantages to work with. Firstly, it was one of the earliest species to appear in its black form in industrial areas. This was about 1848, when *carbonaria* was, for the first time, taken near Manchester. By 1898 approximately 99 per cent of the population were of this form. Professor J. B. S. Haldane has shown that this represents a 30 per cent advantage for this form at this time. Secondly, it is a strong flier, and so the new mutants can spread locally. Recent work I have done this year shows that they frequently fly a distance of two miles and probably more in the course of a night. Thirdly, *betularia* is common both in industrial areas and in unpolluted countryside, and random samples are easy to obtain by assembling to virgin females and the males come freely to light. Fourthly, they are easy to breed except for the privations caused by virus disease, but we manage to hatch about three thousand moths per year.

The life history is as follows: The imago is found from May to August, a long hatching period. The eggs are laid in masses in crevices in the bark of trees. The larvae, on hatching, are wind distributed, hanging at the end of long silk threads. They feed on most trees and plants from June to October. On assuming full growth they descend from the trees at night and pupate in the soil. They overwinter as pupae one to three inches under the soil. The moth hatches early in the evening, thereby avoiding predation for the first day of its life. The newly hatched females assemble males freely from 9 p.m. (G.M.T.) till dawn.

The following is a résumé of the various aspects of the investigations I have been carrying out on the Peppered Moth in an attempt to discover differences between the black and the typical light forms. These differences involve cryptic, behaviour, habit and physiological variations, between the two:

1. *Cryptic differences*. Known numbers of the black form (*carbonaria*) and of the typical have been marked and released into, firstly, an industrial area and, secondly, into a heavily lichened and unpolluted wood, as is still found in certain western and southern counties of England. A deficiency of the more conspicuous of the two phenotypes which occurred among our recaptures was shown to be the result of bird predation. In fact we recaptured two times more of the released melanics in the industrial area of Birmingham than of the released typicals.

Conversely, we have been able to record a reverse situation in unpolluted countryside where the melanic did not normally occur. The camouflage efficiency of the two forms is shown in Plates V and VI.

Table I gives the result of a mark-release experiment in which 630 specimens

TABLE I

Release Experiment figures for Biston betularia (*males only*), *Rubery, near Birmingham, 1953*

The letters C, T, I, stand for *carbonaria, typical* and *insularia*

Date 1953	Releases			Totals	Catches			Totals	Recaptures			Totals
	C	T	I		C	T	I		C	T	I	
25·6	10	12	10	*32*	8	0	1	*9*	—	—	—	—
26·6	0	0	0	*0*	127	15	7	*149*	3	1	1	*5*
27·6	33	11	15	*59*	34	5	1	*40*	1	0	1	*2*
28·6	37	21	5	*63*	23	3	3	*29*	2	0	2	*4*
29·6	0	0	0	*0*	55	10	1	*66*	5	4	0	*9*
30·6	68	26	8	*102*	37	3	2	*42*	1	0	1	*2*
1·7	90	21	3	*114*	76	9	2	*87*	19	2	2	*23*
2·7	74	21	3	*98*	75	13	4	*92*	28	6	0	*34*
3·7	68	15	0	*83*	77	11	10	*98*	25	3	1	*29*
4·7	67	10	2	*79*	66	9	2	*77*	23	2	0	*25*
5·7	0	0	0	*0*	73	3	5	*81*	16	0	0	*16*
Totals	**447**	**137**	**46**	**630**	**651**	**81**	**38**	**770**	**123**	**18**	**8**	**149**

	Catches			Totals
	C	T	I	
Wild Birmingham population .	528	63	30	**621**
Per cent phenotype . . .	*85·03*	*10·14*	*4·83*	
Release after one day of self-determination . . .	25	2	2	
Per cent phenotype . . .	*5·72*	*1·48*	*4·35*	
Per cent return of releases .	*27·5*	*13·0*	*17·4*	

were freed into an industrial woodland. Table II is a corresponding mark-release of 984 specimens into an unpolluted woodland, Dean End, Dorset.

2. We have attempted to assess whether the black and the white forms are capable of choosing correct background on which to rest and pass the day. In order to test this, equal numbers of both forms have been released each night into a large barrel which presented equal surface areas of black and white.

At daybreak they were scored according to where they had taken up position.

TABLE II

Release Experiment figures for Biston betularia (*males only*), *Dean End, Dorset, 1955*

Date (1955)	Releases			Totals	Catches			Totals	Recaptures			Totals
	C	T	I		C	T	I		C	T	I	
(13·6)	(37)	(38)	(9)	(*84*)	—	—	—	—	—	—	—	—
14·6	8	17	2	*27*	4	17	2	*23*	(4)	(1)	(1)	(*6*)
(15·6)	(8)	(25)	(1)	(*34*)	2	27	5	*34*	2	9	(3)	*14*
(16·6)	(22)	(40)	(0)	(*62*)	1	34	2	*37*	(0)	(0)	(0)	(*0*)
17·6	—	—	—	—	7	58	3	*68*	(7)	(7)	(0)	(4)
18·6	42	65	(3)	*110*	0	30	1	*31*	0	1	0	*1*
19·6	39	72	0	*111*	2	26	1	*29*	2	6	0	*8*
20·6	24	57	0	*81*	1	44	2	*47*	1	3	0	*4*
21·6	42	29	0	*71*	1	13	2	*16*	1	4	0	*5*
22·6	—	—	—	—	5	13	1	*19*	5	4	0	*9*
23·6	—	—	—	—	No Releases				No Captures			
24·6	—	—	—	—	No Releases				No Captures			
25·6	82	43	0	*125*	1	11	0	*12*	0	0	0	*0*
26·6	—	—	—	—	3	8	1	*12*	2	2	0	*4*
27·6	51	28	0	*79*	0	8	0	*8*	0	0	0	*0*
28·6	22	22	0	*44*	1	20	0	*21*	1	5	0	*6*
29·6	17	18	0	*35*	0	14	0	*14*	0	5	0	*5*
30·6	24	11	0	*34*	4	11	1	*16*	3	6	0	*9*
1·7	—	—	—	—	2	9	0	*11*	2	2	0	*4*
2·7	—	—	—	—	0	7	0	*7*	0	0	0	*0*
3·7	—	—	—	—	—	—	—	—	—	—	—	—
4·7	55	31	0	*86*	—	—	—	—	—	—	—	—
5·7	—	—	—	—	0	9	0	*9*	0	7	0	*7*
Total	**473**	**496**	**15**	**984**	**34**	**359**	**21**	**414**	**30**	**62**	**4**	**96**

	C	T	I	Totals
Wild Dean End population .	(4) (Possible escapes)	297	17	**318**
Per cent phenotype . . .		*94·6*	*5·4*	
Release after one day of self-determination . . .	2	4	(1)	
Per cent phenotype . .				
Per cent return of releases .	*6·34*	*12·50*	(*26·67*)	

The result is shown in Table III, and by chance this would only occur once in a thousand occasions.

It has, in the past few years, fallen to my lot to witness many hundreds of *betularia* take up their resting positions on trees. It would appear that they choose

TABLE III

Background Recognition in Biston betularia

	Black (= *carbonaria*)	White (= *typical*)	Total
Black background	38	20	*58*
White background	21	39	*60*
Total	**59**	**59**	**118**

a tree at random and then proceed to wander over a foot or so of surface, finally going through the act of turning a circle prior to clamping their wings flat on to the surface. They appear in fact to choose the best local positions available within the few square inches examined.

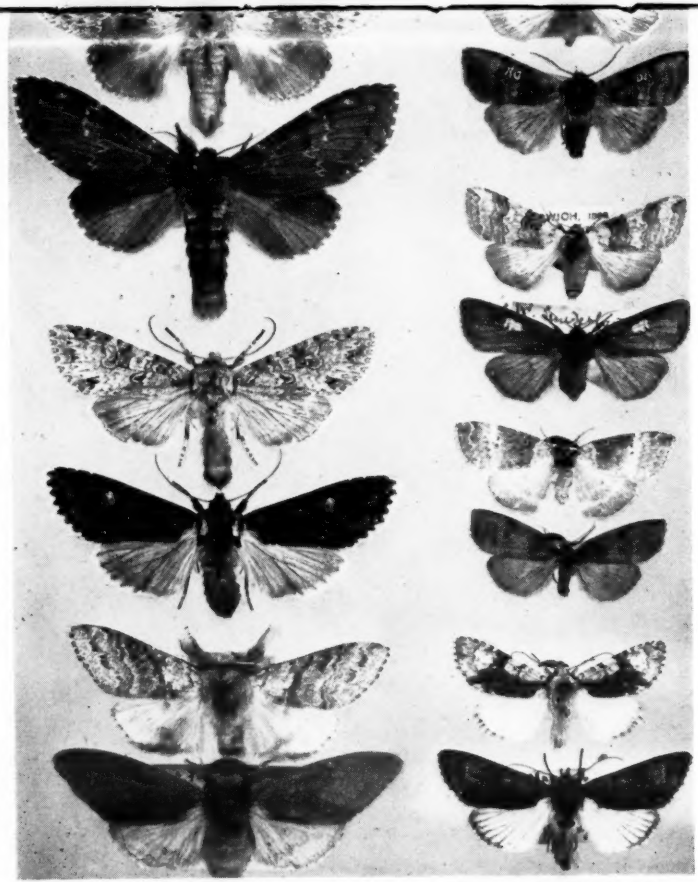
3. We have been able to detect differences in the behaviour of larvae. In certain backcross broods, in which the genetic expectation was that the black and the white forms would be in equality, it was found that those larvae which fed up quickest and pupated first produced a high proportion of the *typical* form. On the other hand, those which fed up slowly and pupated late in the autumn had an undue proportion of *carbonaria*. There can be two interpretations of this. Either the larvae of the *typical* form have been encouraged by selection to feed up more rapidly, thereby avoiding the heavier pollution which covers the leaves late in the year, or the *carbonaria* larvae, by feeding slowly, are able to get rid of the toxic substances present in their diet. Examined in this light, melanism might appear to give the species an opportunity of extending its larval life over a greater number of months of the year.

4. By taking samples of leaves from the same trees at intervals during the summer, we have been able to show that the greater amounts of pollution are present later in the autumn. Besides lateness in the season, there is correlation also between the amount of pollution and the number of aphids present per leaf, their secretion, honey-dew, helping to hold it because of its stickiness.

5. We have attempted to find out whether viability differences existed between the black and white forms. Dr. E. B. Ford has already shown that in another species, *Cleora repandata*, the black form is hardier than the *typical* under conditions of bad feeding and starvation. Using backcross broods, we have fed the larvae throughout their lives on foliage artificially contaminated with pollution obtained from air-filters in London. Under these conditions it appears that more of the black form survive than of the white.

6. Experiments have been undertaken to test whether the newly hatched females of the *carbonaria* and *typical* forms are equally attractive to assembling males. In a short experiment in Dean End Wood, Dorset, where *betularia* are all of the *typical* form and no *carbonaria* occur, I obtained the following results:

Placing cages containing sib-females of *carbonaria* and *typical* six feet apart, the assembling wild males, as they attempted to enter their cage of choice, were captured over fourteen nights. In a total of 129 *typical* males assembled, on warm or cool nights (temp. 55–70° F.), sixty (71 per cent) came to *carbonaria* females and twenty-four (29 per cent) to *typical*. On cold nights, fifteen males came to *carbonaria* females and thirty (67 per cent) to *typical*. On the three nights when the temperature was 65° F. or over, 92 per cent of the males came to *carbonaria* females. It appears,



× ¾ [*Photograph by Michael Lyster*

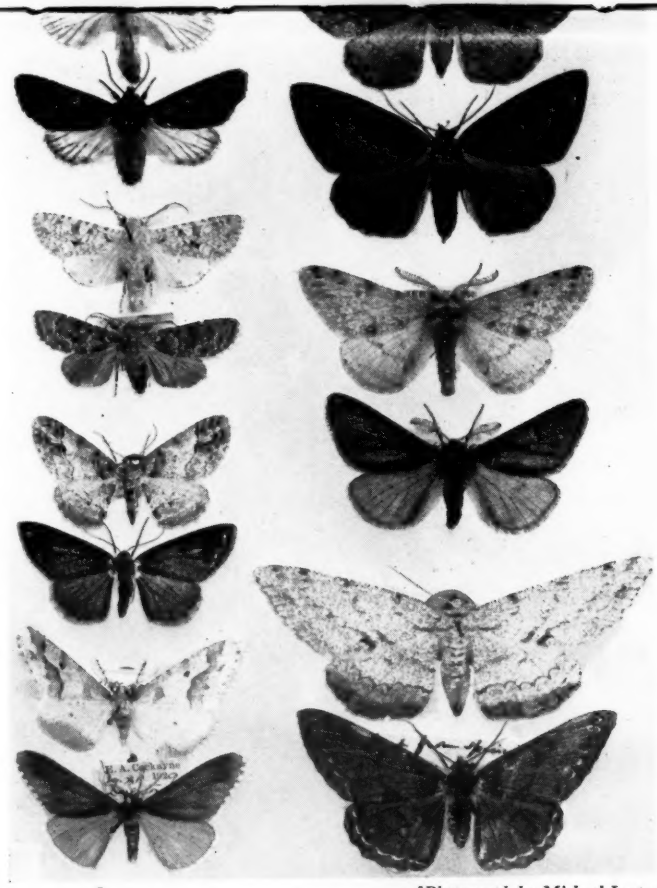
PLATE I

LEFT

1 & 2. *Stauropus fagi* L.
3 & 4. *Polia nebulosa* Hufn.
5 & 6. *Dasychira pudibunda* L.

RIGHT

1 & 2. *Tethea ocularis* L.
3 & 4. *Tethea or* Schf.
5 & 6. *Tethea duplaris* L.
7 & 8. *Apatele alni* L.



× ¾ [*Photograph by Michael Lyster*

PLATE II

LEFT

1 & 2. *Apatele megacephala* Schf.
3 & 4. *Antitype chi* L.
5 & 6. *Ectropis consonaria* Hb.
7 & 8. *Erannis defoliaria* Cl.

RIGHT

1 & 2. *Cleora ribeata* Cl.
3 & 4. *Phigalia pedaria* Fab.
5 & 6. *Boarmia roboraria* Schf.

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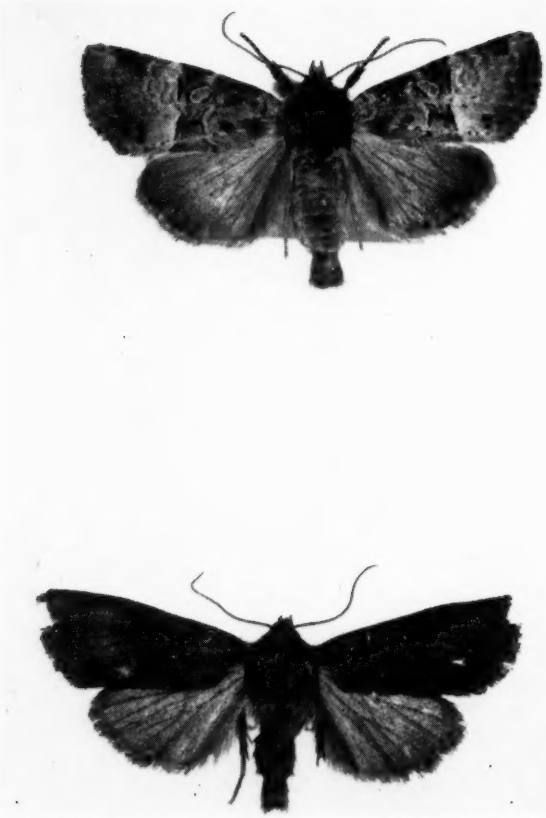

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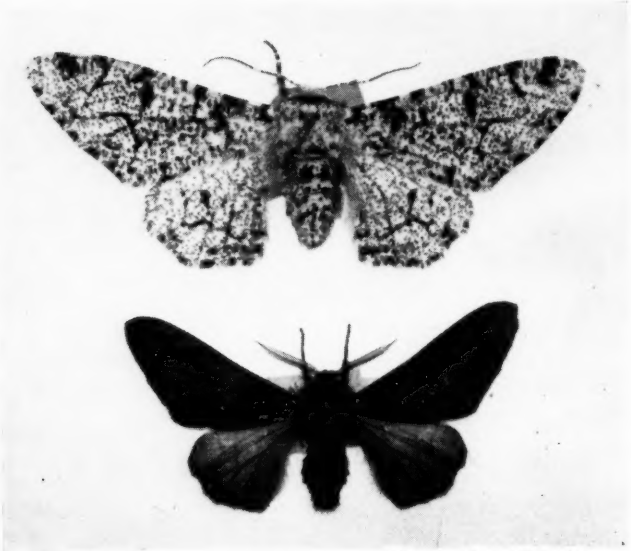
PLATE III

Procus literosa Haw. and its melanic



× 1½ [*Photograph by Michael Lyster*

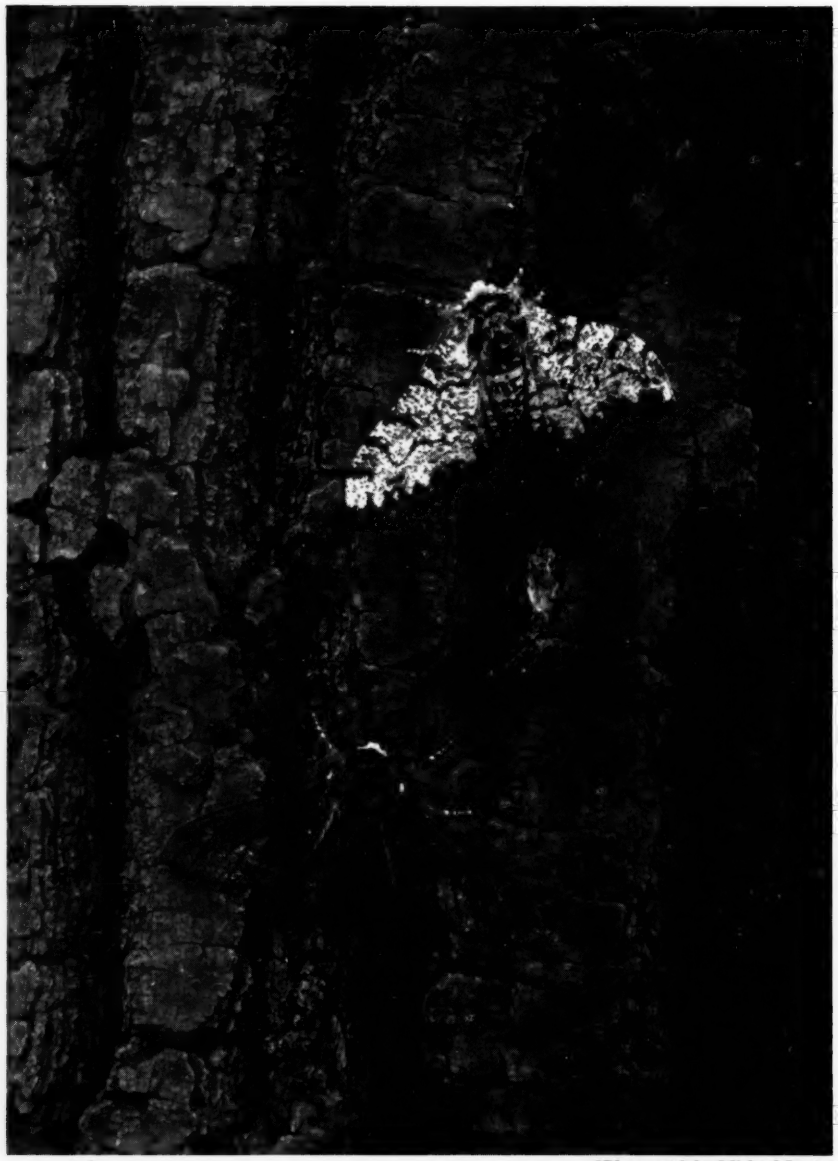
PLATE IV

Biston betularia L. and its melanic f. *carbonaria* Jordan

× 1 [*Photograph by Michael Lyster*

PLATE V

Biston betularia L. and its melanic f. *carbonaria* Jordan at rest on lichened oak trunk



× 1 [*Photograph by Michael Lyster*

PLATE VI

Biston betularia L. and its melanic *carbonaria* Jordan at rest on oak trunk in industrial area

therefore, that there may be behaviour differences, *carbonaria* females being more attractive on warm nights and the *typical* on cold. Alternatively, there may be differences in the actual scent molecule and at the present time we are investigating this using gas chromatography methods.

These, then, are some of the behaviour and physiological differences of the two forms, but I wish to make it abundantly clear that I consider the investigations in this direction in every case not conclusive, and at the present moment these must be accepted as indications of the existence of differences. On the other hand, we have been able to analyse the advantages and disadvantages of the camouflage efficiency of the *carbonaria* and *typical* forms in full. A film which was shown to the British Association demonstrated six species of birds predating the Peppered Moth, and they did this selectively. It is a surprising fact that although Britain boasts of more amateur ornithologists and entomologists than any other country in the world, there have been absolutely no records previously of any bird taking and eating a cryptically coloured moth whilst at rest motionless by day. Dr. Niko Tinbergen, who photographed these experiments and camped with me in the summer of 1955, was able to show in this film that the reason for this was that the act of a bird taking a moth is over in a flash and hence was unlikely to be observed except when under continuous observation. It can, in fact, no longer be doubted that birds most certainly play a part in selective elimination of moths.

It is my contention that, in the recent past, melanic mutations, when they occurred in areas where deciduous trees were heavily covered with lichens, were ruthlessly eliminated because of their colour disadvantages.

We have in Britain, however, a very few small areas where ancient Caledonian pine forests still exist. I have recently returned from working in the Black Wood, Rannoch. Here in this quite unpolluted and unspoilt wood, probably very similar to those which occurred over large areas of Britain four thousand years ago, I found no fewer than seven species of moth with melanic forms in a state of balanced polymorphism. The lichened pines offered two backgrounds: light lichen-covered areas and a darker surface with bare bark. The soil was dark and peaty. Furthermore, beneath the pines were scattered pieces of dark bark and twigs. I decided to concentrate on one species, *Cleora repandata*, and observed just under five hundred individuals of this, of which 10 per cent were black. It has previously been shown by H. B. Williams to be unifactorial and a Mendelian dominant. In my opinion it is identical or possibly an allele of the black form which has practically replaced the normal population in the industrial areas of Lancashire and Yorkshire, and we may in fact have got a link between present-day and ancient melanism.

Repandata is a trunk-sitter; the light forms were always scored as inconspicuous, and the only way I could be sure of seeing and taking a true sample was by fanning each trunk with a net which moved the wings momentarily. By labelling each one early in the day as it rested on a trunk, I was able to find that on occasions over 50 per cent moved during the course of a day. Furthermore, the majority of these took flight because of disturbances by ants or direct sunshine, and at this latitude more than two-thirds of each trunk is exposed to the sun in the course of a day. I saw large numbers on the wing, and myself and three other observers agree that, in flight, the black form is practically impossible to follow, and is invisible over twenty yards distant. The light-coloured *typical* form, on the other hand, is easily seen up to one hundred yards. It is my belief that heavy predation takes place on the wing, and in fact we witnessed three of the light form taken in this way by birds. We have, then, a balanced polymorphism in which the black form at rest is usually more conspicuous than the light. On the other hand, in flight it has a great advantage. I expect to find a similar situation with some of the other species of moths occurring there, and in fact this may be one of several ways in which melanics, in the past, gained advantage.

It is possible now to put forward a theory to fit the case. Four thousand years ago, when Caledonian pine forests stretched down through England, many species existed with their melanic forms in a state of balanced polymorphism, and during this period their dominance was achieved. Since then, however, until recently, conditions, in the absence of pines, were unfavourable for the melanics, which were therefore eliminated. Fresh mutations which took place during this period failed to survive because they were conspicuous on light or lichened backgrounds. Conditions today, though very different to the past, have given the melanics an opportunity because the mutations no longer find themselves at a cryptic disadvantage. Melanism is, in fact, not a recent phenomenon but very old.

PIONEER VEGETATION STUDIES IN THE SOUTH PENNINES[1]

by

PROFESSOR A. R. CLAPHAM

I AM giving this paper at the suggestion of Dr. Ramsbottom, who felt that so much pioneer work in the study of British vegetation was carried out in the southern Pennines that this Sheffield Meeting of the British Association would afford an appropriate opportunity for reviewing the story. There was certainly a most striking concentration of ecological talent in this part of England during the first two decades of the century, and a very great deal of important ecological work was effected. Let us first consider that group of botanists who were the founders of modern vegetational studies in England. You all know, no doubt, the way the tale begins: how a young Scotsman, Robert Smith, who died in 1900 at the age of twenty-six, came under the influence of that versatile genius Patrick Geddes and of that grand old ecologist Professor Charles Flahault of Montpellier and brought to the notice of British botanists, more clearly than ever before, the idea of a vegetational survey as distinct from a floristic. He stressed the superior significance for ecologists of the dominant and abundant species as against the rare or isolated species, developed a concept of a vegetational 'association', and emphasised the adaptational aspect of vegetation. But he departed from the principles laid down by Flahault, and initiated the tradition of British empiricism in ecological matters, by refusing to indicate on his maps the presumed former distribution of forest-types when no trees were in fact present. He preferred to map and describe the grasslands and moors that were actually there. Two parts of his projected Botanical Survey of Scotland were completed before his untimely death and were published in the Scottish *Geographical Magazine*, one on the Edinburgh District and one on North Perthshire, both with maps.

It happened that Robert Smith's brother and collaborator, Dr. William G. Smith, was on the staff of the Biological Department of the Yorkshire College, Leeds, and that his students and disciples included C. E. Moss, W. M. Rankin, T. W. Woodhead and W. B. Crump. A survey of the vegetation of Yorkshire was planned, and work on it began in 1898. In 1902 Moss wrote an account of the moors of South-west Yorkshire, and there appeared a few months later the first English vegetation map. It was published, with an accompanying descriptive account, in the *Geographical Journal* for April 1903, as Part of 'The Geographical Distribution of Vegetation in Yorkshire: Leeds and Halifax District', by W. G. Smith and C. E. Moss. The July number of the same journal contained Part II: 'Skipton and Harrogate District', by W. G. Smith and W. M. Rankin. Meanwhile F. J. Lewis, of the Department of Botany in Liverpool, had been working along similar lines in the northern Pennines, and his 'Geographical Distribution of Vegetation of the Basins of the Rivers Eden, Tees, Wear and Tyne' was published in consecutive volumes of the *Geographical Journal* which appeared in 1904. The first of these also contained a further contribution by Moss: 'Peat Moors of the Pennines: their Age, Origin and Utilization.'

In 1906 came Woodhead's 'Ecology of Woodland Plants in the Neighbourhood of Huddersfield', published in the *Journal of the Linnean Society*. By this time vegetational studies were spreading to Ireland—'The Vegetation of the District

[1] Paper delivered to Section K (Botany) on September 4, 1956, at the Sheffield Meeting of the British Association.

lying south of Dublin (with vegetation map)', by Pethybridge and Praeger, appeared in 1905—and even to the south of this country. When interested botanists met in Leeds on December 3, 1904, the South was represented not only by W. M. Rankin, now working in Portsmouth, but also by a young Cambridge botanist on Oliver's staff at University College, A. G. Tansley. Those present at the meeting formed themselves into the Central Committee for the Survey and Study of British Vegetation. Tansley's famous cycle-ride through the woodlands of South-east England was a direct outcome of the stimulus from the Leeds meeting, and it in its turn led to the publication by Moss, Rankin and Tansley of that account of the woodlands of England, in the *New Phytologist* for 1910, which is the first detailed attempt to consider the distribution and composition of vegetational types in the country as a whole.

The year 1911 saw two events compelling international recognition of the rapidly growing strength of British ecology, for not only did *Types of British Vegetation* appear, but there was also held in August and September of that year the five-week-long International Phytogeographical Excursion of the British Isles, attended by eleven distinguished foreign ecologists. *Types of British Vegetation* was edited by Tansley, who also wrote the introductory chapter and sections on 'Woodlands of South England'. But the Pennine ecologists had more than their fair share of the space, and very notable amongst the contributions was that by Lewis and Moss on the 'Upland Moors of the Pennine Chain', with its descriptions of the Bog-moss and Cotton-grass Associations and its reconstruction of the stages in degeneration of upland bog communities. Moss also wrote the sections on the 'Plant Formation of the Older Siliceous Soils and on the Sub-formation of the Older Limestones', these being based largely on his work in the southern Pennines.

The International Phytogeographical Excursion of 1911 was a great success. It took place in weather which was 'hot and dry throughout, except during three days in Ireland. The health of the party was excellent, scarcely a single member being indisposed during the whole five weeks. In spite of the strenuous nature of the tour, everyone was perfectly fit and well at its close and ready to begin all over again!' On Monday morning, August 7, the party travelled from Holt (Professor Oliver had been demonstrating the Blakeney area) to Derbyshire, driving from Miller's Dale station to Litton, where Dr. Moss met them and showed them the vegetation of Cressbrookdale and Monsal Dale. The next three nights were spent in Manchester, and the two clear days were devoted to the South Pennine moors and woods on the Millstone Grit and Coal Measures, the leaders being Dr. Moss and Dr. Woodhead. On August 10 the Lancashire sand-dunes were visited, and then the party travelled further north, where W. M. Rankin and F. J. Lewis took over as guides.

Ecological studies in the southern Pennines did not slacken after the glories of 1911. Moss's great book, *Vegetation of the Peak District*, was published by the Cambridge University Press in 1913. W. B. Crump's papers on the water-content of peats appeared in 1911 and 1913; in 1915, T. A. Jefferies, a pupil of Woodhead's, saw his 'Ecology of the Purple Heath Grass (*Molinia caerulea*)' appear in the third volume of the young *Journal of Ecology*, and in 1918 R. S. Adamson published his 'Discussions on the Relationships of some Associations of the Southern Pennines', also in the *Journal of Ecology*. I want finally to refer to one further scientific paper on our area, Woodhead's Presidential Address to the British Ecological Society, delivered in January 1927 and published in the *Journal of Ecology* for 1929. Its title was 'History of the Vegetation of the Southern Pennines', and it was a masterly review of the work of the three previous decades on the upland communities of North Derbyshire and the West Riding.

Now I do not propose to attempt to summarise the contribution made by the South Pennine ecologists to the study of British vegetation. But I should like to

refer to three topics to which they devoted a good deal of attention, and, in the manner of some of the more annoying modern novelists, I want to move both backwards and forwards in time from those early decades of this century about which I have so far been talking.

The first of these topics is a very large one: the past, present and future of the extensive upland bogs of the southern Pennines. The composition and distribution of the existing communities was closely studied and well described by Lewis and Moss in *Types of British Vegetation*, and the widespread phenomena of retrogression were illustrated in an excellent and now very familiar series of photographs. But the date of origin of the peat-deposits, the nature of the peat-forming communities and the causes of retrogression remained unsolved or controversial problems. Moss thought the peat mostly post-Roman, believed the peat-forming species to have been throughout those dominating the bog-surface at the present time, with cotton-grass as by far the most important, and ascribed retrogression to a progressive desiccation consequent on the increased drainage of the plateau by the cutting back of the channels of the streams which leave its edges. He knew that this backward cutting had been proceeding very rapidly during the previous eighty years, but he did not suggest why it had not gone further at much earlier times.

Anyone who has reached the top of Kinderscout must be impressed by the deep gullying of the peat and the general atmosphere of decay and desolation; and anyone with ordinary scientific curiosity must appreciate the problems posed by the scene. This was certainly true of John Farey, Senior, Mineral Surveyor, of Upper Crown Street, Westminster, who spent the summer of 1807 and nearly all the next two years in collecting material for his *General View of the Agriculture and Minerals of Derbyshire*, published in three volumes in 1811 for the consideration of the Board of Agriculture. Farey writes:

> Where the limestone hills in Hartington, and others of the elevated parts, have been suffered for a long period to be covered by heath, for want of liming, a thin black wet earth is often formed; but this scarcely deserves the name of peat, when compared with the luxuriant increase of aquatic plants, at some period of the world, on the gritstone heights; for it is a curious and important physical fact that the great part of these immensely thick accumulations of vegetables are not now in activity, but the Mosses present a dead and slowly decaying mass, thinly sprinkled with heaths, aquatic grasses, &c.; and yet enough of them in every part is now increasing, in the lower and wetter parts, both to show that the growth of this peat belongs to the present state of our planet, and to indicate the species of plants which composed the peat now dead. It is abundantly evident that the humidity of the atmosphere on these elevated planes of strata has been sufficient to keep up the growth of aquatics for long periods of time, after they had once been adapted to the growth of large trees of our present species, of which the remains are now in most places found, under great thicknesses of dead peat (crossed in all directions by Gullies or Groughs). . . . And peat, though it often contains wood, is evidently not composed of ligneous plants in any instances which I have seen or heard accurately described . . . but is formed of great accumulations of the grey bog-moss (Sphagnum palustre), cotton-grass (Eriophorum polystachion), heaths (Ericas), marsh horse-tail (Equisetum paulstre), rushy bents and other aquatic small plants which can still be seen growing on the edges and wetter parts of the most black and rotten of these elevated peat mosses.

Professor Pearsall has drawn attention to the significance of this passage in placing sphagna first in the list of peat-formers. It is not quite clear whether Farey did in fact recognise dead remains of sphagna in the peat, but it seems almost certain that he did so. And his reference to the continued formation of peat by the same species in restricted wetter areas suggests strongly that living sphagna were much more conspicuous in his day than now, aiding him to a truer understanding of the composition of the peat-forming communities than Moss achieved. Impressive, too, is his emphasis on the long period of high atmospheric humidity following upon a time when large trees of species still growing at lower altitudes were able to

flourish almost to the summits of the gritstone heights. Finally, it is interesting to note that degeneration must have been well under way in his time, with deep gullies or groughs crossing the peat in all directions; and Farey tried to find an adequate explanation. He observed, he writes,

> in passing along the western edge of Stanage Moss, that the firing of the heath on the first grit at the edge of the bog had at different periods set fire to the peat, into which it continued to penetrate and make large irregular holes, apparently, until heavy rains fell to extinguish it: this source of unevenness, and of the groughs and gullies, and of local dead black places on the surface of these mosses, is perhaps more common than has been supposed. . . .

Farey did not attempt any estimate of the age of the deep peat deposits beyond stating that its growth belonged to the 'present state of our planet' and post-dated a period when familiar species of trees were able to grow high up on the hills.

Woodhead, in his Presidential Address of 1927, finally disposed of the theory that the peat was all post-Roman by describing the observations made by himself and Richmond on the Roman road at Blackstone Edge, which at the point examined was laid on twenty-two inches of peat. He also reported the numerous finds in the south Pennines of Mesolithic microliths in the humus-stained sand at the base of the peat, and of Neolithic, Bronze and Roman remains within the peat. The inference that the basal peat must have been largely formed during the Atlantic period was supported by some rather inconclusive pollen diagrams published in the previous year by Woodhead and Erdtman. But Woodhead still talked of 'the insignificant part played by bog-mosses in the formation of the peat', and for the final confirmation of Farey's view, as of Woodhead's on the age of the peat, we have had to await the investigations of Professor Pearsall and Dr. Verona Conway, carried out during the past fifteen years or so.

The second of my topics is the vegetational type called 'calcareous heath' by Moss. In his *Vegetation of the Peak District* he refers to high-level grasslands over limestone, at altitudes of more than 1,000 ft., in which 'a certain number of heath-loving or humus-loving species, such as *Luzula multiflora*, *Potentilla erecta*, *Polygala serpyllacea* and even *Ulex gallii*, and also a certain number of lime-loving species, particularly *Poterium sanguisorba*, may occur'. And he claims that 'the superficial soil of such localities is comparatively poor in lime, even when the subsoil consists of limestone and . . . even when there are no glacial or other foreign deposits. Doubtless the soil, in the course of ages, has had much of its lime carried away in solution'. And where the lime-content of the superficial soil is still lower, *Calluna* and *Vaccinium* may occur and justify the term 'calcareous heath'. But he says that these heaths are rather meagrely developed in the district.

Farey is most informative on this point. He tells us that:

> Heath of the common sort (erica vulgaris: i.e. *Calluna*) is much too common. It abounds on all the moors and on most of the remaining commons in this county, in a less or greater degree. Within a few years past nearly all the fine limestone hills between Ashbourne and Buxton were occupied by heath, which is now happily becoming rather scarce there; and when the only remaining commons or unimproved lands in this calcareous district, in Middleton, Youlgreave, &c. shall have been inclosed, pared and burned, and limed &c., this noxious and useless plant will, I hope, disappear altogether from this district.

The same picture is given in *Peak Scenery or The Derbyshire Tourist*, by E. Rhodes, 1824. Of Tideswell Top, he writes:

> I recollect passing over this particular place in the year 1813. It was then a heathy moor; not a shrub or blade of grass. . . was to be seen. I now revisited the same ground, the same geographical spot of earth, but so differently clothed that every trace of what it has been was obliterated. . . . The sterile waste had vanished, and in its place a sea of corn, far

as the eye could reach, waved plenteously around . . . the plenteous cornfield has succeeded to the bleak and heathy moor.

It must surely be inferred that 'calcareous heath' was once very widespread all over the limestone plateau and that in the early years of last century most of it was reclaimed, though whether for the first time is not clear. The method of reclamation was either by heavy liming alone, a very slow process; or, much more usually, by paring with a paring-shovel or breast-plough, which a man shoved before him, followed by burning the thin turves and liming heavily. Then a crop of turnips was taken, and in the next year oats and grass seeds were sown. Liming might be deferred until after the turnips had been taken up. Of the shale soils of Edale an earlier writer, William Bray (1777), states that after recovery from heather by paring and burning, the local farmers take two or three crops of oats and then sow down to grass for six or seven years, after which they plough, lime and crop with oats again, repeating the 8–10-year rotation. There was probably no need to plough as frequently as this on the limestone, provided lime was applied often enough; and Farey thought it certainly unnecessary to pare and burn periodically, a practice he abhorred, observing that, where it was permitted by landlords,

> the greatest slovens and worst managers oftenest resorted to its use; just as the most idle and improvident most frequently apply to the stimulating effects of strong liquors; and the subject for emulation among paring and burning farmers of this description too commonly is who shall soonest obtain an herbage of weeds and paltry on his land, as the pretence for, and the means of, a fresh ignition.

If so much of the limestone plateau was heath-covered at some time in the not very distant past, it becomes a matter of considerable interest to know whether the lime-free surface soils were the product of leaching *in situ* or whether they commonly indicated an accession of material from elsewhere. There is now a strong suggestion that the soils in question are indeed products of leaching *in situ*, but more work is needed before a definite statement is possible. But whatever their precise interpretation from this standpoint, the communities transitional between the limestone grassland of steep slopes and Moss's calcareous heath of the plateau are interesting in themselves and pose numerous intriguing autecological problems.

The third of the topics to which the work of the south Pennine pioneers directs attention is autecological research. In his 1906 paper Woodhead selected a group of species prominent in the woodlands near Huddersfield and discussed their distribution in relation to geological substratum, topography, light intensity, etc., and the effect of varying conditions on their anatomical structure. More familiar is his demonstration of the different effective rooting-depths of bracken, bluebell and *Holcus mollis* in what he termed the 'complementary association' of sessile oak-woods. Nine years later it was a pupil of Woodhead's, Jefferies, who published the first full-scale autecological study, that on *Molinia caerulea*, based on fieldwork in the Huddersfield district.

You may not expect it to be possible for me to claim that the old agricultural writers anticipated even this aspect of the pioneer work of this century. Yet I am prepared to make the claim, again on behalf of John Farey, in respect of his scattered observations on *Calluna*, which he called *Erica vulgaris*, or Common Heath. His index has under 'Heath, Ling or Ericas' the two entries: 'are worthless and most detrimental plants', and 'are exterminated by profuse liming'. Turning to the pages indicated, one may read:

> Where the Heath . . . has long been suffered to continue without molestation . . . the soils . . . are subject to what they call Fox-earth, a ferruginous and barren substance, found like a pan or floor a few inches beneath the surface. It seems to confirm the ingenious suggestion of Mr. H. Holland that it is formed by the deposition of oxide of iron in

the filtration of ochrey water, and to shew, as I have long thought, that the Ericas, and some other plants peculiar to barren ochrey soils, generate or collect the oxide or iron

(he is somewhat off the target here). He goes on to explain that this pan must be broken before trees can be planted successfully on such soils, and concludes that 'the above observations tend strongly, I think, to shew that the sooner these noxious plants, the ericas, are banished from our soils, the better for ourselves and posterity'. Elsewhere he offers 'a few Memorandums that I made on the herbage of these disgusting Moor Lands' and proceeds to give brief accounts of *Vaccinium myrtillus* and *vitis-idaea*, *Oxycoccus*, *Empetrum*, and *Erica cinerea* and *tetralix*, all the accounts having a strong ecological flavour.

During the past ten years or so we have in this department undertaken several autecological investigations and others are still in progress. You will be hearing accounts of some of this work, and other items will be shown in the demonstrations.

My time is up, and I must stop. I have tried to show that ecological problems of our area which were so successfully attacked by that stalwart band of local botanists who founded British vegetational studies at the turn of this century, were often recognised and considered by members of a remarkable group of agricultural scientists working a century or more earlier. And it is aspects of these same problems that are the main concern of Pennine ecologists today.

THE INTERNATIONAL GEOPHYSICAL YEAR[1,2]

by

PROFESSOR SYDNEY CHAPMAN, F.R.S.

THE EARTH AND ITS CHANGES

OUR great globe the earth, on which we dwell, rolls onward, like the other planets, around the far greater sun. The sun moves together with its family of planets and comets among its fellow stars of the Milky Way. This turns majestically around its centre. Beyond lie myriads of other galaxies. Light and radio waves traverse the vast intervening spaces. The recognition of this immense perspective in space is one of the collective triumphs of the human race.

The earth is small by such standards, but to us it is great. It has seen the rise and fall of continents, and the wonderful drama of the evolution of life, culminating in the development of man, the lord of the earthly creation. Much has been done to trace out the earth's eventful history. We seek also to glimpse what the future holds in store for the earth and our race.

Man's search after knowledge has brought to light many aspects of Nature that our senses alone cannot detect—such as the magnetism of the earth, and the wonders of the atom. Man has also been quick and resourceful to use this knowledge for his own purposes—with untold promise for our good or our destruction. Much of this knowledge has been gained in the laboratory, but our knowledge of our planet cannot be completed only there. We must traverse it and measure it on the spot, in its many parts and in many ways. The task of mapping the earth is almost done, but the air and its ways, the seas and their ways, affect our lives deeply, and we must continue to observe and try to understand the laws they follow. This kind of knowledge is called geophysical.

THE ARCTIC AND THE TWO POLAR YEARS

While the trade and influence of Europe spread over the world, to the equator and beyond, the Arctic near at hand remained little known. Voyagers did, indeed, search for a north-west passage, and brought back with them some knowledge of the geography and the physics of that region—of the weather, the beautiful northern lights, and the surprisingly strong magnetic disturbances that occur there. But these casual additions to knowledge, from one place one year, and from another place another year, gave but little understanding of Arctic physics.

A young Austrian lieutenant, Weyprecht, who had been on an Arctic expedition in 1872, saw that to get a better understanding of the Arctic weather and physics there must be a number of *simultaneous* expeditions. He spread this idea, and it was finally realised in the enterprise called the International Polar Year, 1882/3. Unhappily he died before his dream was thus realised.

In August 1882 eleven nations sent expeditions to remain in the Arctic for thirteen months. Their observations of weather, of the northern lights, and of the magnetic changes were afterwards published in a number of large volumes. To this day they are a treasure store of Arctic knowledge. This Polar Year added greatly to our understanding of the Arctic. But like most scientific quests, it disclosed new fascinating problems for further study.

[1] Evening discourse delivered on September 3, 1956, at the Sheffield Meeting of the British Association.

[2] Chairman of the Central International Committee appointed to organize the IGY; staff member of the Geophysical Institute of the University of Alaska, and of the High Altitude Observatory, Boulder, Colorado.

Half a century passed away. Science advanced greatly in many directions. A few polar expeditions, to the south as well as to the Arctic, added to our knowledge of the polar regions. But they were not simultaneous, and so they added less than they might have done.

At last it came to be felt that a new Polar Year was needed. This came to pass in 1932/3, fifty years after the first. Again the main effort was in the Arctic, where twenty nations sent expeditions. Britain reoccupied the station Fort Rae in northern Canada, where its expedition had been fifty years before. Canada, much developed in the half-century between the two Polar Years, established Arctic stations of its own.

In the Polar Year II there were more stations than in Polar Year I. The observations were also better and more extensive. Improved magnetic instruments were used. The polar lights were photographed as well as observed by eye. The weather men had new tools. Their measures were no longer confined to the air near the ground. They sent up balloons carrying instruments that signalled their measurements by radio to the ground.

Another new departure was the exploration of the Arctic ionosphere—the region in the upper atmosphere that is electrified or, as we say, ionized; this is important to man because it enables radio waves to travel round the curve of the earth to long distances. A British station to study the Arctic ionosphere was set up at Tromsö in northern Norway. The leader was Professor (now Sir Edward) Appleton. It began the discovery of the many remarkable properties of the ionosphere in the region where the aurora appears.

The International Geophysical Year (IGY)

In April 1950, less than twenty years after the end of Polar Year II, it was proposed that there should be a third Polar Year after twenty-five instead of fifty years. The proposer was Lloyd Berkner, a distinguished American scientist, one of the pioneers in exploring the ionosphere. His suggestion was made and welcomed at a small evening party of American scientific friends whom I met in Washington on my first visit there after World War II. Our host was Dr. Van Allen, whom I shall mention again later. A main argument for a third Polar Year was the advance in techniques of observation of many kinds, partly stimulated by World War II; another was the increasing importance of the Arctic in radio communications and air travel.

Later in 1950 Berkner and I presented formal proposals for a Third Polar Year to an international scientific committee, headed by Sir Edward Appleton: they were favourably received and usefully extended. Next, the proposals were brought before other more comprehensive international scientific bodies, and then to the top level body, the International Council of Scientific Unions, of which Berkner has since become President, in 1955. In 1951 this Council decided to form a special committee to organise a third international Polar Year; in 1952 the nucleus of the committee was appointed. Invitations went out to all nations, inviting their co-operation. Later in 1952 the plan was extended so as to cover the physical study of the whole earth instead of only its polar regions. Thus the proposed Polar Year III developed into the International Geophysical Year, commonly known in English-speaking countries as the IGY.

In 1953 the committee was enlarged and held its first planning meeting, at Brussels. By then twenty-three nations had decided to join, and some of their representatives aided the Committee in drafting the first programme of the work to be done. It was decided that the IGY should extend from July 1, 1957 to the end of 1958—actually a year and a half.

A second planning meeting was held at Rome in 1954; by then thirty-six nations had joined, including Russia. Alike under Czar and Soviet, Russia had taken part

in the Polar Years, giving full and valuable co-operation. A third planning meeting was held, again at Brussels, in 1955, by which time there were more than forty participating nations. Tomorrow I fly to Barcelona for the fourth and last great planning meeting; the number of nations now agreeing to take part in the IGY is over fifty. One of the main matters to be discussed is the handling of the immense amount of data that will be gathered during the IGY. There will be a number of world centres at which the material will be collected, and from which serious workers who wish to study it can obtain copies. There will also be centres of such studies, which will not be completed until some years after the IGY is ended.

The proposal for a co-operative physical study of our planet is a simple one. Its appeal has proved to be great. Never before have so many nations joined freely together in so great an enterprise of peaceful scientific research. If the undertaking is to be complete, the aid of all nations is needed. Only each nation, or others willingly invited by it to work on its territory, can study the ways of the earth over its land. Not every nation has joined, and the programmes of different nations are not equal. Each does what it will and can. Each bears the cost of its own programme, though there will be many gifts or loans of instruments by one nation to another. Only the expenses of the IGY central committee and its organising meetings are borne internationally, principally by the International Council of Scientific Unions and by the United Nations Educational, Scientific and Cultural Organization (UNESCO). These expenses form only a tiny fraction of the whole sum that will be spent on the IGY. The central secretariat is at Brussels, in charge of the eminent Belgian scientist Dr. Nicolet.

The IGY Programme

At the outset, the plan of research was intended to cover observations of weather, of magnetism, of the polar lights or aurora, and of the ionosphere. The earth's magnetism, the aurora, and the ionosphere, are all greatly affected by the state of the sun, as revealed by sunspots and other solar features. Hence, improved solar observations were included in the plan. Later the programme was extended much beyond these limits. It became necessary to lay down principles to govern the choice of new proposals for the programme. The primary purpose continued to be the study of those aspects of the earth that change rapidly, and for which widespread *simultaneous* observations were needed.

But the possession of world-wide weather data, and magnetic and ionospheric observations, is of great value in aiding some other branches of geophysics—in studying the physics of the oceans, and the size and form of the whole earth, and the glaciers of the globe. Hence these subjects were brought into the programme, and also, for the same reasons, the study of the cosmic rays, those particles of matter from outer space, some of which are at this moment penetrating the whole atmosphere and the roof of this building, and passing through the bodies of each one of us. They are of great interest in themselves, and as they are affected by changes on the sun and in the earth's magnetism, they can tell us something about our planet and its near surroundings.

These subjects form the main IGY programme. Some other earth sciences, of great importance and interest, lie mainly outside this programme. One is the study of earthquakes, which are practically independent of weather and the sun; it can gain little from the great mass of observations I have mentioned. However, the IGY observations will involve ocean and land expeditions to the Antarctic and remote islands, and other places where the passage of earthquake waves has been little studied, or not at all. Where possible, these expeditions will record earthquakes during the IGY. Likewise they will measure the gravitational pull of the earth, which will tell us something about its form and the distribution of mass within it.

Thus the programme now includes world weather, the earth's magnetism, the aurora, the ionosphere, the sun, cosmic rays, the better determination of latitudes and longitudes (to improve our knowledge of the form and size and geography of the earth), glaciers, the oceans, earthquakes, and the pull of the earth on objects near its surface.

This programme is too extensive to be described here, even in outline. I can touch only on some outstanding aspects of it.

Antarctica

One of these concerns Antarctica. Many famous expeditions have visited that distant continent, for periods of a year or so. There have even occasionally been more than one expedition there at the same time—as when Scott's race to the south pole, that ended so tragically, was forestalled by Amundsen. But during the IGY the Antarctic will be *populated*, by about twenty expeditions on the continent itself, and many others on the outlying islands. The nations that will have stations on the continent will be Argentina, Australia, Belgium, Chile, France, Great Britain, Japan, New Zealand, Norway, Russia and the United States.

The IGY will be for the Antarctic far more than the first and second Polar Years were for the Arctic. Many more men will do scientific work there, of much greater range. They will have more and better instruments, and improved living conditions. Aircraft as well as surface transport will help to set up and supply the stations. Nevertheless, there will be isolation and danger, and these studies of the lonely south will involve great effort and expense.

As there has been no permanent settlement of the Antarctic continent, it has been necessary to send out exploring parties to study possible sites. This began already four years ago. Some expeditions have already started their scientific work, before the IGY officially begins next July; at some stations the work will continue into 1959.

Here it is right that I should mention specially the British effort in the Antarctic. Great Britain will have eleven IGY stations at *permanent* settlements south of 51° S. latitude. It will have one major *expedition* on the continent. This is organised by the Royal Society, at a bay in the Weddell Sea, newly named Halley Bay, after the great English scientist whose comet comes within sight of the earth every seventy years or so; the third centenary of his birth is being celebrated this year.

The Royal Society advance expedition sailed from Southampton last November. On arriving off the Antarctic continent they made a search for a suitable site for their station. In January this year they unloaded their stores near the chosen site. Their ship returned to England, leaving ten men behind. By the end of May, amidst frequent blizzards, they had erected their buildings, put their stores under cover, and begun a limited programme of observation. Since then they have experienced months of Antarctic darkness. Next November the main British party, of eighteen men, will leave England, with further equipment.

With them will be the members of the British Commonwealth Trans-Antarctic expedition. This also sent an advance party last year, and chose an offshore site called Shackleton Base, about 200 miles from Halley Bay. Next winter they will occupy this site and make weather and other observations for some months. They will also set up an inland observing station nearly 300 miles to the south. In November 1957 they will leave both their stations and cross the continent by way of the south pole, where one of the American expeditions is to be settled. The 1,800-mile journey of the Trans-Antarctic party will bring them to a New Zealand station on the Ross Sea. From this station Sir Edmund Hillary, conqueror of Everest, will lead a party to set up a chain of depots to support the oncoming men on the last part of their journey. These men, travelling by snow vehicles, will make weather and

glacier observations, and will probe the thickness of the icesheet, each 20 miles or so along their path, by echoes from explosive charges.

At the end of the IGY far more will have been learnt of Antarctic conditions than was learnt about the Arctic during the Polar Years I and II. The geography will not have been fully explored, but the last unknown continent will have given up many of its mysteries—with what consequences for mankind cannot yet be foretold.

The Weather Programme

Weather is one of the most vital influences on the life of man. The atmosphere is immensely complex in its ways. These have been deeply studied only over a small fraction of the globe. Air travel has made it necessary to extend the study to greater heights, and to regions where there was formerly no organisation for the purpose. But there remain great gaps in our knowledge, especially for the regions over the oceans, despite the good work of the few weather ships, and of many island stations and of the reports from ships. Hence the study of weather will be an outstanding part of the IGY programme.

A major problem of weather and climate is the movement of air between the tropics and higher latitudes, and at different levels. The large-scale and smaller-scale circulation of the atmosphere will be specially studied, by surface and balloon observations. Great efforts will be made to send the balloons up to 100,000 ft. over much greater areas than have so far been explored up to this height.

The jet streams, those swift rivers flowing in mid-air, that encircle the earth in each hemisphere, will be studied. Their high speed—often of the order of 100 miles an hour—greatly affects aviation, and their changing sinuosities are linked with weather over large areas.

Special attention will be given to the tropics and the southern hemisphere, where our present knowledge is most defective. The World Meteorological Organisation, an agency of the United Nations Organisation, will play a large part in this programme.

Oceanography

The oceans, covering three-quarters of the earth, powerfully influence weather and climate. They absorb heat from the sunlight, unequally in different latitudes. This sets up ocean currents. Some are great rivers in the sea, like the Gulf Stream. Others involve slow interchanges affecting greater depths. The overturning of the water in these circulations affects its fertility and our food supply. Knowledge of these deep interchanges may also be important when nuclear energy becomes widely used for peaceful purposes; if much radioactive waste matter has to be disposed of, it is important to know whether, and how best, the oceans can safely be used as a dump; this will depend on how widely and quickly the material will be dispersed by the circulation.

The tidal changes of level will be studied at coastal and island stations more numerous than ever before. They will also record the approach of the long waves set up by distant storms in mid ocean.

In addition there will be many ocean expeditions to measure the temperature, the salinity and other chemical content of the water, and the ocean currents. The ocean survey vessels will also take weather and other observations, perhaps including magnetic ones, and they will study the structure and composition of the sea bed. The chemical analysis will include the amount of carbonic acid gas dissolved in the water. Man's burning of fuel in the last century has increased the carbonic acid gas in the atmosphere by about 10 per cent. This may have long-term effects on world climate. But the oceans are a great regulator of this gas in the air, hence the need to study how much of it they contain.

Glaciers

Glaciers now cover about 10 per cent of the land area of the globe. In the past they have at times extended over thrice this area. They lock up a vast quantity of water in solid form. The melting of many former glaciers has raised the sea level, and much affected the boundaries of the continents. Future changes of this kind may profoundly affect the human race.

The glaciers are mainly in high latitudes, but they are found in all latitudes, including the tropics. During the IGY many expeditions will map them and study their present state. Besides the British glacier studies in the Antarctic—on the main continent and the Islands—British scientists may also study the glaciers elsewhere, for example, in Africa and Greenland.

Concentration of Effort in Space and in Time

Even with the wide co-operation between nations during the IGY, however, it will not be possible to make fully comprehensive high level observations of the atmosphere over the globe all through the IGY. Hence, though the IGY itself represents a great temporary concentration of effort in *time*, a further concentration will be made both in space and in time.

As regards further concentration in *time*, there will be three special days per month, already chosen before the IGY begins, on which meteorological and other kinds of IGY observations will be intensified. These will be called Regular World Days. On these days the meteorologists will make special efforts to launch more balloons, and send them higher than they may be able to do every day.

In addition, for the weather men only, special weather intervals of ten days each will be included in each quarter-year, for more intensive observations.

The concentration in *space* consists in choosing a number of limited regions for special effort, in many branches of IGY studies. Five chains of stations will be set up along special meridians. Three of these chains will extend from pole to pole. One will traverse Europe and Africa, at about 10° E. longitude; another will traverse America at 70°–80° W., and the third will cross Asia and Australia at about 140° E.

There will also be zones, as in the tropics, to which special attention will be given.

Special World Intervals (SWI)

Some earth phenomena are profoundly affected by the state of the sun, as shown by sunspots and otherwise. No major effect of sunspots on *weather* has yet been established. The earth phenomena most clearly affected are the earth's magnetism, the aurora, the ionosphere and the cosmic rays. It is important to give special attention to these when storms on the sun produce magnetic and ionospheric storms on the earth. Unlike weather storms, these affect the whole world simultaneously.

Storms on the sun cannot be predicted long beforehand. During the IGY the sun will be watched more continuously, and with more and better means, than ever before. There will be a chain of solar observatories girdling the earth, and perhaps a watch on the sun from the Arctic during its season of continuous daylight.

The sunspots, magnetic fields and other features on the face of the sun will be observed, and also the edge of the disc. There the fiery storms surging up from the sun's surface can best be seen. The radio waves from the sun will also be measured.

The spots and storms on the sun wax and wane in an eleven-year cycle. The IGY will be a period near sunspot maximum, hence we can expect much solar activity.

During the last sunspot maximum, in 1946, remarkable events on the sun were photographed at the high (11,200 ft.) solar observatory at Climax, in Colorado, U.S.A., with which I am privileged to be connected. The films which were taken showed fiery solar gas shooting upwards or descending. This gas is not travelling

towards the earth, but similar fiery fountains, not so easy to see, shoot out in our direction, from the face of the sun.

When the sun is seen to be so spotted and disturbed that the earth seems likely soon to be affected, an international IGY agency will issue warnings or Alerts. They will be the signal for many observers to check their instruments and be ready to pay special attention to any magnetic or ionospheric storm that may occur. If such earth storms are judged to be imminent, the international agency will announce a Special World Interval for the intensive study of these sun-affected phenomena. These studies will continue till the warning agency calls a halt.

This will be an additional IGY concentration of effort, for special types of study, during intervals that cannot be foretold many days in advance.

The Aurora

The Alerts and SWI will be specially valuable in the watch for the aurora. This is a beautiful spectacle of Nature, and one of great scientific interest. Unlike many other earth phenomena, it can be observed without special instruments, though such instruments can add much to our knowledge. But anyone can see the aurora, just as anyone, with smoked or dark glasses, can see whether there are big spots on the sun.

In high latitudes, as in Alaska, where now I usually spend some of the winter months, the aurora is a common sight. But so infinite is its variety that its beauty never becomes stale. In other parts of the world it is less often seen. Unfortunately many people miss the occasions when they might see it—they may be indoors, or clouds or city lights may obscure it.

The aurora is our most direct evidence that sunlight is not the only means by which the sun affects the earth. Sunlight shines only on half the earth, and twilights a narrow zone around the edge. The aurora is certainly caused by the sun, which sends out electrified or ionized gas. This travels to the earth much more slowly than light—in about a day instead of ten minutes, as for sunlight. When the gas comes near the earth, some of it is deflected by the earth's magnetism round to the back of the earth—the dark half—and towards the magnetic poles. The details of this motion are not understood—to the scientists it is a teasing mystery. We are eager to probe it, not only for its own interest, but also because the aurora is linked with other events, like magnetic and ionospheric storms, that closely concern human affairs.

The mystery is greatest when these storms are most intense. Then the aurora becomes visible from lower latitudes than usual—from England, or even, much more seldom, from the tropics.

For these most interesting of all auroras the observations are very incomplete. They appeared unexpectedly, and were seen only by chance. Many who saw them may have admired or feared the unfamiliar appearance in the sky, but failing to realise what it was, did not record what they saw. We need to learn more about these remarkable auroras, by photographs and careful descriptions by those who see them.

In the polar regions, and indeed also in Scotland, there will be many special cameras that will photograph the whole sky; they will do so automatically, at frequent times throughout each night. At many stations, at least during Alerts and SWI, the photographs will be taken every minute. This will give a wonderfully complete record of the auroras in the higher latitudes, where they appear most often.

In lower latitudes the aurora is visible too seldom to warrant such all-sky cameras. But we hope that more people than ever before will see and record the auroras that become visible there. It is too much to expect many people to watch nightly for something that seldom appears. But the IGY warnings of likely

disturbances on the earth, based upon the events seen on the sun, should here help greatly. It is hoped that the newspapers and the broadcasting services will inform the general public of these warnings. This should enable many to see one or more auroras during the IGY, who would otherwise miss them. This is one of the few ways in which non-specialists can directly help the scientists during the IGY, if they will carefully watch and record what they see.

Thanks to Mr. James Paton of the University of Edinburgh, the plans for the observation of the aurora over the United Kingdom are in excellent shape. He is also Director of the Auroral Section of the British Astronomical Association. He has organised wide and instructed co-operation between amateurs, weathermen and other scientists, and seamen and airmen. Canada, Australia, New Zealand, Russia and the United States also have well-organised plans to observe the aurora. I hope that the British survey will be extended to all the far-spread territories and islands of the Commonwealth; with our world-embracing sea and air services, we can make a major contribution to this fascinating and important part of the IGY.

Rockets

The auroral light comes from high in the atmosphere—60 miles or more. The air has other interesting physical and chemical properties there, that we wish to know. We can find out much by observations from the ground, by radio and other means. But measurements on the spot can tell us still more. Balloons cannot reach those heights, but rockets can. One of the notable new features of the IGY will be the abundant use of rockets to explore the high atmosphere.

Some of the German war rockets, of which in this country we have sad memories, were captured and taken to America. There after the war some of them were used to explore the upper air. When the supply ran out, new rockets better suited to such peaceful purposes were designed. Since then the Americans have had this field of atmospheric research to themselves. With great energy, skill and expense they have used rockets to increase our knowledge of the upper atmosphere. They have also added much to our knowledge of those parts of the sun's rays that are absorbed in the high atmosphere—mainly the ultraviolet and X rays from the sun. They can only be observed by going into or above the layers that absorb them, and shield us from them. With rockets the Americans have also explored the earth's magnetism and the cosmic rays at high levels. Van Allen, in whose home in 1950 Berkner proposed that 1957/8 should be a third Polar Year, has done brilliant research in the auroral regions of the atmosphere, by rockets launched from balloons—or rockoons; this saves much expense, by carrying the rockets slowly through the most retarding layers of the air.

During the IGY the United States will undertake the lion's share of the rocket programme. But it is hoped that at least a few other nations will contribute to it, namely Australia, France, Great Britain, Japan and Russia.

In this country, in co-operation with the Royal Society and under the Ministry of Supply, the Royal Aircraft Establishment has designed a promising research rocket. An interesting programme of observations and experiments with these rockets has been planned; it is hoped to carry this out during the IGY.

Earth Satellites

Valuable as rockets are, in being able to observe on the spot at great heights, they have one great drawback—they stay for so short a time in those high regions.

In 1954 the international committee for the IGY learnt that there was a possibility of an earth-satellite being designed and launched during the IGY. The committee expressed great interest, and the hope that this could and would be done, as it seemed clear that an earth satellite might make valuable and unique contributions to geophysical knowledge.

The American scientists informed their government, which authorised the large expenditure and effort needed to develop the satellite.[1]

Last year the White House officially announced that a satellite would be launched during the IGY. Early this year many details of the satellite plans were made public.

The first satellite will be a sphere about 20 inches in diameter. With its instruments its weight will slightly exceed 20 lb.; about half of this will be for instruments within the sphere.

It is to be launched from an Air Force base on the coast of Florida, in a direction about 40° south of west. A three-stage rocket will launch it. The first stage, taking two minutes, will give it a speed of three to four thousand miles an hour, at forty miles from the launching site. The second stage will carry it to a height of about 130 miles, and raise its speed to 11,000 miles per hour. The last stage will carry the satellite to a level of about 300 miles, and set it in its free course, subject only to gravity, with a speed of about 18,000 miles per hour.

In the free orbit the height of the satellite may range between 200 and 1,500 miles, and its latitude is intended to range between 40° N. and S. The earth will rotate beneath the satellite. Each time the satellite crosses the equator southwards, it will be 25° further west. Such crossings will occur about every hour and a half. If the satellite is successfully launched, it will stay high in the atmosphere for many days or weeks—till the slight air resistance slows it down, and it descends and burns up in the denser air below, like a meteor. While it is aloft, it will pass over most of the band of latitude between 40° N. and S., covering more than half the globe. From places where it passes nearly overhead at dawn or sunset it may be visible to the unaided eye for a few minutes, and readily visible with binoculars. It may not, however, be visible from this country. The United States invites co-operation from other nations in observing the satellite, by eye and by radio reception of the signals transmitted from within it. These may have a range of up to a few thousand miles in all directions, and may be detectable from this country.

The problem of making worthwhile observations by instruments within so small a satellite is a difficult one, and not too much can be expected from the first satellite. But the history of rocket exploration gives confidence that the problems will be progressively solved, and will add greatly to our knowledge. Still more, it may be guessed that the launching of the IGY satellites will be a landmark in man's progress towards space travel.

Other Parts of the Programme

My time draws to its close, yet I have said scarcely anything about many important parts of the programme—of the network of magnetic and ionospheric observatories over the globe, that will tell us much that we wish to know about the ionisation, the winds, and the electric fields and currents in the high atmosphere and beyond; nor of the cosmic rays, whose origin is still mysterious, though they are at times much affected by storms on the sun, as in February of this year; nor of new and special observations of the moon, that will fix the distances between the continents more exactly than before, and in future centuries may help to decide whether the continents move relative to each other.

To go into more details would be too long and too technical. But I hope I have given you some idea of the scope of this great enterprise.

The IGY Symbol

The IGY will bear fruit in immense numbers of books and articles enshrining and discussing the observations. It has been decided that these may bear a distinctive

[1] Note added Jan. 1957. At the Barcelona conference referred to above, it was announced that the USSR would also launch IGY satellites; and co-operative arrangements were made with the USA delegation so that the same ground detection apparatus might be used for both sets of satellites.

symbol; perhaps the satellites will also bear it. Only a few outstanding aspects can be illustrated by the symbol. The symbol chosen shows the earth, half sunlit, half dark, illustrating in the simplest way the influence of the sun. The south pole is shown, to emphasise the specially great advances the IGY will bring to Antarctic knowledge. The satellite is shown, to illustrate the most novel and striking of the many new instruments to be used during the IGY.

International Co-operation

The IGY has been well called a great symphony of science. It is a symphony that is, and must be, international. Each nation has a part that only it can play. All nations are welcome and needed partners in it—though certainly the absence of some minor performers will not spoil the music.

It is an essential feature of the IGY that all nations joining in it will make their observations the common property of all. In time all nations will benefit from the results. In these troubled days it is good to find an undertaking in which so many differing nations willingly and harmoniously combine together in a task so peaceful and beneficial.

GEOLOGY IN SCHOOLS

Report presented by a Research Committee of the British Association for the Advancement of Science at the Annual Meeting held in Sheffield, August 29 to September 5, 1956.

Composition of the Committee: Prof. T. N. George (*Chairman*), Dr. Mabel E. Tomlinson (*Secretary*), Prof. J. G. C. Anderson, Miss M. A. Arber, Mr. A. Bray, Dr. J. F. Kirkaldy, Prof. L. R. Moore, Mr. J. Myers, Sir William Pugh, O.B.E., F.R.S., Dr. K. S. Sandford, Dr. S. H. Straw, Dr. Dighton Thomas, Dr. A. K. Wells, Prof. A. Wood.

General

THE preparation of this report has been undertaken by a committee of the British Association in an attempt to set out ideas and suggestions that might be helpful to the increasing number of schools which are introducing Geology into the curriculum, either as a main subject or as an ancillary to other sciences. The subject is already taught on a formal basis in a number of Secondary Grammar schools but it also has opportunities in Secondary Modern schools, which are more free from the control of external examinations. It gives opportunities for experimental work and deductive reasoning. Special laboratories and apparatus are not essential.

The subject has a strong appeal to most pupils, especially in schools which have reasonable access to the countryside or to good museums. Pupils acquire an appreciation of their environment which may well extend beyond the classroom and may lead to Geology being taken up as an interest when school life is left behind. If its only place were in cultural education for leisure, Geology has strong claim to be more widely taught in schools.

In Secondary Grammar schools Geology is more usually taken in the fifth and sixth forms for General Certificate of Education. In 1955 (the date of the latest available figures) there was a total of 797 candidates (including 166 girls) entered for G.C.E. Ordinary level and the percentage pass was 61.7. The number shows a marked increase over the 392 candidates in 1952. At the Advanced level 391 candidates (including 51 girls) took the examination, the pass being 85.2%. The number entered for Scholarship papers was 111. In 1952 the number of Candidates entering for Advanced level was 291. The number of State Scholarship holders taking up Geology in 1955–6 was 19, whilst there were 50 holders already following courses in Geology.

In Further Education, Geology forms part of the courses for National Certificates in Mining and Mining Surveying and for qualifications in Civil and Structural Engineering. It is also an ancillary subject to Degree courses in Chemistry and other sciences. These courses are usually taken in Technical Colleges. There is also a certain amount of Extra-Mural and W.E.A. work in Geology. The work of institutes of Further Education is not considered in this report. Courses in geology specially designed for teachers are offered in certain of these institutions.

I. Primary Schools

In Primary schools formal instruction in Geology is out of place, but, depending on facilities and opportunities available, Geology may offer an occasional lesson or demonstration, e.g. when a borehole is being drilled in the neighbourhood, when local rocks are used for roadstone or brick-making or when mineral workings occur nearby. Interest could be extended by discussions of the movement of underground water, the flow of wells and the significance of sea shells in rocks. Children's

pleasure in collecting could be used to encourage a broad discrimination between one rock type and another and to give some meaning to rocks and fossils.

II. Secondary Schools

(A) NON-SELECTIVE OR MODERN SCHOOLS

These schools are a comparatively new development in secondary education, and have great flexibility and freedom to experiment in method and syllabus. The age range is from about eleven to fifteeen years and children showing great variation in ability may be found in them. In addition to the imparting of factual knowledge, it is desirable that courses in such schools should develop an experimental approach to learning and train the powers of observation and reasoning. In this aim, Geology is of considerable help, especially when the member of staff concerned in teaching the subject is keen and is willing to devise experimental work and to encourage field studies.

The subject should not be treated narrowly but should include aspects of Chemistry, Physics and Biology. Industrial applications should not be forgotten. Mathematics should be used as it arises and measurements taken in the field could form the basis of calculations in the Mathematics lessons. Field work, accurate recording and the collection of specimens are essential. It is often stated that country schools are the only ones that can easily do field work. This is not so. Most towns contain stone quarries, clay pits or open-cast workings within easy reach of schools, and road sections and cuttings provide constant sources of information. Some schools take Geology as an independent subject whilst in others it forms part of Geography, Science, Social and Rural Studies, Gardening or Campcraft courses. The Art courses in one school have produced some excellent fabric printing designs based on stylised representations of fossils.

EQUIPMENT AND ACCOMMODATION

For the necessary field work the main requirements are hammers, small collecting bags, one or two tape measures and simple clinometers for measuring the dip of strata. (The clinometers can be made from ordinary celluloid protractors with a small plumb-bob suspended from the centre.) For practical work a classroom would be satisfactory especially if it had gas and water points and horizontal tables, though a demonstration room or a science laboratory would be better. The chemical reagents needed are simple and safe and consist mainly of dilute acids.

STAFF

It is unlikely that specialist staff will be available but an increasing number of teachers with some knowledge of Geology is likely in the future. Great specialisation is unnecessary and may not be an advantage at this level. What is desirable, however, is enthusiasm, ability to devise practical and experimental work and a willingness to read widely in the subject.

SYLLABUSES

Suggestions for a syllabus for a Geology course are given below. They are merely suggestions, since balance and emphasis will depend on the objects of the school courses, the interests of the teaching staff and the nature of the local geology. It will be noted that other sciences are treated as they arise in the work.

Rocks such as *limestones*, *sandstones* and *shales* occur in most areas and are likely to be known to most pupils. These sedimentary rocks could form the basis of practical work at the beginning of the course.

In dealing with *limestones*, the effects of acids could lead to a consideration of the properties of CO_2, the products of respiration, black damp in mines and the

composition of air. The solubility of limestone in natural waters may introduce a discussion of hard and soft water, and the possibility of having acid soils residual from limestone rocks can be touched on. Exercises in calculation are provided by dissolving the lime from a limestone and estimating the percentage of insoluble residue in the rock. Some idea of the origin of limestones could be given especially if the local examples are fossiliferous. Industrial uses, cement and lime manufacture, lime in agriculture and as roadstone should not be overlooked.

With *sand and sandstones* the shape, size and packing of the grains, together with their relations to permeability and porosity, is important. The angle of rest of loose sands in damp and dry conditions provides material for experiment. The formation of sandstones by the introduction of cementing material and its effects on porosity lead to capillarity experiments, to show the difference between sandstones and shales in the movement of ground water. In the field, bedding can be observed and interpreted. The use of sand and sandstone for building, with emphasis on local samples, can be indicated.

With *clays*, *muds*, *shales* and *marls*, texture and fineness of grain may lead to discussions on plasticity. Shrinkage on drying and firing provides exercises in elementary calculations. Changes of colour and loss of plasticity on firing allow comment on the uses of shales and marls in brick making and the pottery industry. The impermeability of shales and its control on the occurrence of lines of springs may often be linked with historical and geographical studies of settlements.

In chalk districts the occurrence of flint nodules could serve to introduce the topics of flint implements and the use of flint in the pottery industry and as a building material.

In most industrial towns a variety of topics arises out of the geology of *coal*, e.g. the rocks of the Coal Measures; the organic origin of coal; the products of burning; gas, coke and coal as a source of energy and raw material in the chemical industry.

Igneous rocks do not offer the same facilities for experimental work, but pupils should know something of the crystalline nature of these rocks as a result of solidification from the molten state and analogy with the making of crystals in chemistry is appropriate. A few examples such as granite and basalt suffice for simple demonstration.

Fossils, as the remains of organisms and their relationship to the enclosing rocks, always interest children. Simple ideas of evolution could be gained from comparison with living animals and the changes that occurred during geological time. The *accurate* sketching of fossils is an invaluable exercise.

Evidence of former *glaciation* can be seen in many districts. In these areas boulder clays can be examined and a varied collection of rocks be made. The direction of movement of ice in Britain during the ice age could be discussed.

In dealing with *water supply* the relationship of porosity and permeability should be taken. Rain as a source of water, gathering grounds, solutes in water, hard and soft waters, shallow and deep sources of water, pollution, water tables and springs are all important.

EXCURSIONS

Excursions to localities near the school should be used for observation of outcrops and measurement of dip and strike and stratal thickness, for the interpretation of land forms, for sketching geological structures and for collecting specimens.

The essential feature of a scheme such as the above is that it should be treated as a source of observation and experiment. Limestones, sandstones and shales brought in by the pupils form the basis of work which should be carried out by the pupils themselves and only to a limited extent by the teacher. Practical and field work is suggested in a later section.

GENERAL SCIENCE

In a course of General Science, Geology takes its place equally with Chemistry, Physics and Biology. It is best treated as it arises naturally in the syllabus rather than as a separate entity sandwiched between other sciences. In discussing water the usual biological and chemical observations should be supplemented by a discussion of the origin of calcium salts that make water hard. This leads to questions of circulation of water within rocks, cementing material of rocks, springs, porosity, permeability, etc. In the standard experiment of using Iceland Spar or marble to produce carbon dioxide limestone could be used instead. Experiments with magnets could possibly lead to a brief outline of the earth's magnetism and magnetic methods of ore finding. Fossils could be used to illustrate the succession of life on the earth and to show that geographical and climatic changes have taken place. If the question of fissionable material comes up, discussion of the age of the earth may follow. In dealing with metals, sources and origins of ores could be discussed.

RURAL SCIENCE AND LOCAL STUDIES

Geology is helpful in Rural Science and Local Studies courses and the following subjects might be considered for inclusion—weathering of rocks; limestones; joints and water circulation; effects of acid rainwater on rocks, especially in town atmosphere; the iron, lime and silica cements of sandstones and the relationship of the cementing material to the type of weathering; the acidity of sandstone soils. Much practical work can be done, and examination of local buildings will often show the effects of weathering and frosting on different types of stone in different situations. Water supply is important in Rural Science and special consideration should be given to areas of possible pollution and to the effect of dip on the travel of polluted water. The origin of soils and their possible relationship to the underlying solid rock is important; whilst glacial deposits form interesting topics. It may be possible to demonstrate a change of vegetation with a change in type of underlying rock. The relationship of scenery and geology and the geological controls on settlements and industries should be stressed.

CAMPCRAFT

One of the objects in campcraft courses is a knowledge of the countryside, and emphasis should be perhaps on the interpretation of landscape as in the relationship of rock hardness and folding to the development of hill and valley. The general physical geology topics usual in geography courses are important. Field work in camping should be mainly on types of rocks forming hills and valleys, glacial features, origin of lakes and siting of villages.

FIELD WORK

The collection of specimens is an important part of any work in Geology. A mere collection of stones, however, is of little value. The pupils should record the locality where collected, if possible on a map kept at school, and the specimens should be labelled. If a permanent school collection is being built a geological map of the area is invaluable but the teacher may need to simplify and generalise Survey maps to make them not too difficult for class use.

Field work is essential and will provide much material for class use. Several visits to one locality to see one thing at a time may be more beneficial than a single general visit.

Where outcrops and road cuttings are available, the strata exposed might be measured and changes in lithology and stratification noted. Vertical sections of the strata can then be drawn to scale. Cuttings on one side of a road may be compared with those on the other and some attempt at correlation be made. Where escarpments occur, an outcrop map may be related to the topographical map to show that

the rock of the escarpment is harder than that of the valley. Lines of villages are frequently sited along the foot of an escarpment where water seepages occur at junctions of pervious and impervious rocks. The seasonal variation in the stand of water in wells may be studied. Sands and gravels and boulder clays may be examined in drainage ditches and in the overburden of quarries.

Measurements taken during field work may be used as a basis for exercises in calculations. Measurements of outcrop width and angle of dip may be used to work out true thickness and depth of strata at fixed surface locations. Measurement of depths of valleys from contour maps may be used to measure the amount of material excavated in denudation. Fossils offer opportunities in drawing, and landscape work in Art lessons may be improved with some knowledge of Physical Geology.

(B) SELECTIVE OR GRAMMAR SCHOOLS

During the last twenty years there has been a big expansion in the teaching of science in Secondary Grammar schools notably in Chemistry, Physics, Biology and General Science. As yet Geology is taught in comparatively few schools, though the number is increasing. Nevertheless, Geology has strong claims for inclusion in the Grammar School curriculum and should take its place along with the other sciences. There is a connecting link between all sciences. The student of Physics, Chemistry and Biology will find that some knowledge of Geology provides a wider approach and a more comprehensive foundation to the study of his special subjects; and in its ramifications and in the manner of its impinging upon most other sciences, it is the most completely integrative of the scientific 'subjects' and might well occupy a central place in the teaching of General Science. The connection between Geology and Geography is so close that it is difficult to give adequate instruction in the one without also teaching the other.

PLACE OF GEOLOGY IN THE SCHOOL CURRICULUM

It being taken for granted that Geology could be introduced with advantage into schemes of General Science teaching, the framing of suitable syllabuses should offer no great difficulty and could be achieved with little alteration of timetable. At many points, matter introduced into the teaching of Chemistry, Physics and Biology is closely related to Geology and by a moderate extension can be given a wider scope. The study of water could well be extended to include water supply with its bearing on the types of rocks from which underground water may be obtained, and on those likely to produce hard or soft water. A knowledge of the chief types of rocks and their resultant soils would be of value in the study of plant ecology. Collections of plants from the vicinity of the school could be made of wider interest to the pupil who knows something of the nature of the underlying rocks and soils. The study of some of the common minerals, their mode of occurrence, and their characteristics provides a broader basis for their study in the chemistry lessons. Most General Science syllabuses contain some reference to evolution which can only have meaning if extended to include some study of fossils. Economic Geology might also be added and could include the origin of coal, petroleum, salt, gypsum and any mineral which is significant in local industry. Physical Geology, though finding an appropriate place in Geography, could be used, with some co-operation, to make the General Science and Geography syllabuses supplement each other.

SYLLABUS OF ELEMENTARY GEOLOGY FOR INCLUSION IN THE GENERAL SCIENCE COURSE

It is not the purpose of this report to suggest a rigid syllabus of Geology for inclusion in the General Science scheme. The details of such a syllabus should be conditioned by the particular needs of the school and by the manner in which

the various aspects of General Science are integrated. The geology of the school neighbourhood should obviously determine the bias given to the teaching.

EQUIPMENT NEEDED FOR ELEMENTARY GEOLOGY

No expensive equipment need be purchased for teaching Elementary Geology in grammar schools. The following are regarded as desirable:

Geological hammers, lenses, geological map of Great Britain, geological map (1-inch) of the area adjacent to the school, a carefully chosen collection of geological specimens together with suitable accommodation so that labelled specimens may be handled by the pupils.

GEOLOGICAL SPECIMENS

It is suggested that the collection should include common rocks, minerals and a few characteristic fossils from the principal geological formations, especially those of the school neighbourhood. This might form a basis on which a larger collection could be built by adding specimens collected by pupils from their home locality, and, during holidays, from other areas. The choice of fossils should if possible include at least one representative from each of the more common phyla. The list of specimens which is given below is merely illustrative: different choices might be more suitable for particular schools.

SUGGESTED LIST OF SPECIMENS

Rocks: granite, basalt, schist, slate, marble, sandstone, conglomerate, shale, limestone, chalk, coal.

Minerals: calcite, fluorspar, rock salt, quartz, feldspar, mica, hornblende, iron pyrites, haematite, galena, azurite, graphite.

Fossils: characteristic specimens representing life in each of the Geological Systems.

ADVANCED SIXTH FORM COURSE IN GEOLOGY

Pupils who take an advanced course of geology in the sixth form will probably offer it as a subject at advanced or ordinary alternative level in the General Certificate of Education examination. Many of the examining bodies set papers in geology at all levels in this examination. Some pupils who study geology in the sixth form may do so because their interest has been aroused in the elementary course but without the subject having any particular bearing on their future career. Others may study the subject for vocational reasons; such pupils would include those who hope to become teachers of geography, civil or mining engineers, and those who aim at becoming professional geologists.

UNIVERSITY REQUIREMENTS FOR ENTRANTS TO GEOLOGY SCHOOLS

During the last few years this committee has investigated the requirements of those pupils who take an advanced course of Geology at school, with a view to entering a University to read for a degree in Geology. The committee has obtained information from the Universities as to the requirements of intending entrants to University Geology schools. There is a consensus of opinion that such intending entrants should have a good scientific background. It is generally expected that subjects offered at the advanced level of the General Certificate of Education should be chosen from the following: Chemistry, Physics, Biology, Zoology, Geology and Mathematics. A further enquiry has shown that a large percentage of candidates offer Geography in addition to Geology in their entrance examination. While the close connection between these subjects makes the combination reasonable, it should not exclude the study of such sciences as Chemistry, Physics, or Zoology,

which are regarded by the Universities as fundamental to an honours course in Geology.

It is essential that headmasters and headmistresses should consult the calendar of the appropriate University as to faculty and departmental entrance requirements.

GEOLOGICAL CAREERS OPEN TO GRADUATES

At the moment there is a demand for trained geologists especially overseas. Only pupils of high promise should be advised to apply for entry to University schools for Geology since it is generally necessary for a student to gain a good honours degree if he is to stand a chance of obtaining a post as a professional geologist.

EQUIPMENT FOR ADVANCED COURSES IN GEOLOGY

Geological maps should include the following: Map of the British Isles; 10 miles to the inch maps of England and Wales and Scotland; 1-inch map of area surrounding the school; several 1-inch maps of selected areas in Britain.

The collection of geological specimens should be more extensive and varied than that suggested for the elementary course. It should also include specimens showing rock structures. Advanced level syllabuses of the General Certificate of Education are issued by seven Examining Bodies. In some of these the knowledge of the use of a petrological microscope is required, in others it is optional. However, even where direct questions on microscopic petrology are not set in the examination paper, it is desirable that pupils should have some elementary experience in microscopic work. A suitable student model of a petrological microscope may cost £70–£80. It is probable that a school may be able to acquire only one such model, in which case a micro-projector would prove of great value in class demonstration. A small collection of microscope slides may be purchased. It is suggested that the chosen slides should include the following:

Igneous rocks:	granite, dolerite, quartz porphyry, basalt, gabbro, obsidian, rhyolite, coarse tuff.
Metamorphic rocks:	schist, slate, marble, gneiss.
Sedimentary rocks:	oolitic limestone, shelly limestone, chalk, greywacke, sandstone, shale, coal.

GEOLOGICAL FIELD WORK

Geology is fundamentally an observational science dealing with phenomena seen in the countryside. Field excursions should therefore form an important part of geology teaching. If possible, excursions should be organised to enable the pupils to gain a first-hand knowledge of the geology of some selected area. Some schools are better placed for field work than others but it should be possible for all schools to organise day or half day excursions to areas of geological interest. By arranging the timetable so that a whole afternoon is given to Geology, localities beyond the vicinity of the school may be more readily visited. For longer excursions Field Study centres might well be used.

THE GROWTH OF BIOCHEMISTRY[1]

by

PROFESSOR F. G. YOUNG, F.R.S.

BIOCHEMISTRY as a subject of significance in University life, and in science in general, has expanded enormously during the past ten years, but for nearly half a century before that it was gradually creeping into University curricula and becoming accepted as an entity in itself. The introduction of a new subject into universities is usually a slow process, but since nearly a dozen new professorships have been founded since the war in Great Britain alone, the growth of biochemistry in recent years is indeed a rapid one.

WHAT IS BIOCHEMISTRY?

Before the growth of biochemistry is considered, a definition of the subject should perhaps be given, although I myself am no great believer in the value of definitions. A dictionary, which defines words in terms of each other, must necessarily be a vicious circle. In any case any dictionary which is sufficiently up to date to include the word, is usually uncertain whether a hyphen should be included in 'biochemistry'. The name of the subject which I am considering has no hyphen.

Biochemistry may be defined as the study of the structure and function of living matter on a molecular basis; it is largely concerned with the manner in which living organisms achieve chemical change. Defined thus, and always in practice, it overlaps on one side the biological sciences in general and physiology in particular, while on the other side it intermingles with chemistry, and even physics and mathematics. Although this overlap exists, the primary aim of the biochemist can be differentiated from that of a chemist on the one hand, and from the classical biologist on the other. The chemist is mainly concerned with pulling to pieces molecules, the identification of the fragments he so obtains, and the artificial production of the structures which he thus deduces. An organic chemist does not become a biochemist if the molecules in which he is interested are of biological origin, since he is not primarily concerned with the organisation and function of biological systems but with the structure and properties of molecules. The physical chemist, and to a less extent the organic chemist, is interested in the way that chemical reactions start and progress and the mechanisms involved. In so far as such processes go on in biological systems they are of interest to the biochemist, but the physical chemist, or the organic chemist, is, of course, not primarily concerned with reactions such as go on in biological media, and in general he prefers to study reactions under much more simple conditions than obtain in a biological system.

The biochemist resembles the organic chemist in possessing an interest in the structure of molecules, but he is primarily and particularly concerned with: first, how the chemical configurations which have been deduced from chemical work may be incorporated into the construction of a biological system; and second, how molecules may be built up or broken down in such a system, and how such changes affect the system. A biochemist looks at biological problems with the general eye of a biologist, but with the analytical interest of a chemist. Although the classical biologist is also interested in the organisation and function of biological systems he is not concerned with them mainly or initially on a molecular scale. Nor is the biologist usually interested in the intimate chemistry of the processes involved in the

[1] Evening discourse delivered on August 31, 1956, at the Sheffield Meeting of the British Association.

maintenance and function of a biological system, matters to which the biochemist is dedicated.

It is my belief that at heart biochemistry is one of the biological sciences, the core of the subject being the study of complex dynamic systems of biological origin under controlled conditions. These complex systems, having been separated from living organisms for examination under defined conditions, are sometimes described by the ordinary biologists as unphysiological remnants of what was once a living organism, while those concerned with physics and chemistry, or at least some of them, have often looked upon them as messes which are not susceptible to controlled investigation. Undisturbed by these depressing comments the biochemist has gone ahead with the belief, admittedly, sometimes nothing more than an assumption, that what he is doing has biological significance, and with the conviction that the pattern of a biological system is not so complex as to resist analysis in terms of chemistry and physics. So far the assumptions and the convictions of biochemists have been fully justified.

Biochemistry and Organic Chemistry

Early last century what I have just said about biochemistry would have described what might well then have been considered to be the function of organic chemistry. How, then, did biochemistry come to development as a subject which at present can be differentiated from organic chemistry, although it is to be hoped that the gap between the two will diminish as the years go on?

Until the end of the seventeenth century the interests of chemists, with one or two notable exceptions, of which Paracelsus and a few other iatrochemists were the most outstanding, had been directed largely to an examination of the substances occurring in the non-living mineral world. But in the *Cours de Chymie* (1675), written by the French chemist and physician, Nicolas Lemery, the arabic classification of substances into the three 'kingdoms', 'animal', 'vegetable' and 'mineral', was adopted and substances which occur in plants and animals were considered properly to fall within the scope of chemical investigation. During the eighteenth century many substances derived from vegetable, and to a less extent from animal sources, were isolated and their properties studied, but little or no attempt was made to carry out these investigations in a systematic manner. The results were in general classified according to the origin of the substances and to miscellaneous properties of them, rather than on the basis of what we now understand as chemical relationships. Because of their association with living organisms, that is with 'organised' matter, the products of the animal and vegetable worlds were termed 'organic' substances, in order to distinguish them from 'inorganic' materials, which made up or which could be formed from inanimate matter.

Antoine Lavoisier, the great French chemist who lost his life in the French Revolution, found that organic substances are composed largely of the elements carbon, hydrogen and oxygen, together sometimes with nitrogen and, less frequently, phosphorus and sulphur. Since respiration in animals was found to involve an oxidation of carbon and hydrogen to carbon dioxide and water (1785), Lavoisier came to the conclusion that 'life is a chemical function'. Nevertheless, most chemists still held the view that the power of building up elements into the complex substances which occur in the living organism is the sole prerogative of a special vital force or vital energy inherent in the living organism.

In 1828, however, the apparently unbridgeable chasm which seemed to separate the inorganic from the organic world, was crossed by the discovery of Wöhler that when an inorganic salt, ammonium cyanate, was heated it was transformed into urea, a substance which occurs in urine and which up to that date had been known only as a product of the metabolism of animals. As Wöhler himself wrote to

Berzelius in 1828, 'I can make urea without calling on my kidneys, or indeed without the aid of any animal, be it man or dog'. This discovery attracted rather little attention at the time and, indeed, Wöhler himself was somewhat uncertain of its significance. Moreover, this synthesis remained the only one of its kind for a good many years. So it was not until about the middle of the last century, when the artificial production of other organic substances began to be successfully carried out, that belief in a vital force and in the existence of a fundamental difference between inorganic and organic substances was abandoned. It was about this time also that the term 'organic' began to lose its original connotation and to be applied to the apparently limitless compounds of carbon, whether these substances were derived from living matter or not.

The Development of Organic Chemistry in the Nineteenth Century

The achievements of organic chemistry during the first half of the nineteenth century, particularly in Germany, were spectacular.

One would have expected that with the rapidly growing subject of organic chemistry as a driving force, the investigation of the chemistry of processes in living systems, biochemistry in essence, would have grown apace during the nineteenth century. Nevertheless it is disappointing, but true, that a large proportion of chemists, particularly of those in Great Britain, remained unconcerned by the possibilities of investigations in the field of biology. The chemical structure of many of the substances of importance in biological process was too complex to yield quickly to the analytical processes then available to chemists; moreover, the attractions of synthetic organic chemistry began to multiply and the rich prizes that appeared in the shape of synthetic dyes, perfumes and fabrics, proved to be strong. And so in the second half of the nineteenth century the advances in the chemistry of substances of biological importance were as meagre as they were spectacular in the first half of the twentieth century.

In a challenging paper entitled 'The Mystery of Life' read to the British Association at the meeting in Glasgow in 1928, Professor F. G. Donnan, who happily is still with us at the age of 86, surveyed some of the developments of last century and of this, which had up to that time led to our knowledge of the fundamental physico-chemical processes underlying life. As he then pointed out, the progress of biochemistry had been foreshadowed by Claude Bernard, the great French physiologist, who hoped, during the middle decades of last century, by a patient exact and quantitative application of the facts and laws of physics and chemistry to the elementary phenomena of life, gradually to arrive at a synthesis and understanding of the whole. It is at once an interesting and sad reflection that during the nineteenth century almost no British chemist or physicist of international reputation turned serious attention to the study of the phenomena of life, and particularly to those of animal life, despite the fact that so many distinguished Continental chemists found, in biology, an irresistible attraction. One has but to name in Germany, Liebig, Wöhler, Pettenkofer, Voit, Hoppe-Seyler and Emil Fischer; in Sweden, Berzelius; in France, Pasteur, Lavoisier, Dumas, Claude Bernard (although he is commonly regarded as a physiologist, he was particularly concerned in some of his investigations in the application of chemical knowledge to biological problems) and Pasteur; in Great Britain, Thomas Graham in 1862 showed that the particles of a colloidal solution would not pass through a parchment membrane, and applied this method of analysis to biological material, while later in the century (1860–80) Thudichum, an immigrant from Germany, laid the foundations of our knowledge of complex fatty materials. At the time it was done Thudichum's work was largely ignored, while Thomas Graham's researches had no strong effect on the development of animal chemistry in Great Britain at the time.

Why did British chemists so widely ignore the possibility of applying their knowledge to biological systems in general and to animal metabolism in particular? No simple answer can be given to such a complex question as this, but it is of interest to note that the cherishing of household pets, which is such a conspicuous aspect of the Englishman's habits today, seems to bring itself to notice from about the early years of last century. This development on a national scale of a sentimental affection for animals, leading as it did to strong anti-vivisectionist movements, may well have held back many who might otherwise have applied their scientific aptitudes to the experimental investigation of animal life.

Why the British began to develop such a love of household pets during the past century is a question more for social historians than for biochemists. But it may well be significant that this trait appears when the urbanisation of the population was rapidly proceeding, and the grim realities of the farmyard were being left behind. It seems not unreasonable to suppose that the humanitarian movements in the early part of the last century, concerned for instance in the emancipation of slaves and in the successive reform bills, may be related to a growing attachment for animal life. But this is only speculation.

Another factor that undoubtedly contributed in the latter part of the last century to a stunting in Great Britain of the potential development of experimental biology (in which biochemistry may be included) were the controversies that captured the imagination of many thinking people after the publication of Charles Darwin's *Origin of Species* in 1859. Those who were engaged in relentless verbal battles about matters which clearly could not be settled by experiment were less likely to turn to the application of chemistry and physics to the phenomena of animal life, than those who were not taken up in such speculative animosities. To me it is illuminating that when Pettenkofer and Voit decided to investigate the heat production of the animal body, they came to London to obtain a Thomson calorimeter, in 1860, because in this country calorimetry had been so highly developed. But little interest was taken in this country, either at that time or subsequently, in the application of the calorimeter to the measurement of animal heat.

Enzymes

During the past century the development of ideas about ferments, or enzymes as we now call them, was of paramount importance in the growth of biochemistry. Alcoholic fermentation is a process that has been known for as long as men have been civilised, or even longer. The fact that such a fermentation normally depends upon the presence of a living system was not realised until the discovery of Cagniard-Latour, in 1836, that yeast is a living organism.

During the seventeenth and eighteenth centuries it had already become known that digestion in the gastro-intestinal tract of animals and birds takes place by a process which is akin in some respects to fermentation. In 1782 the ingenious Abbé Spallanzani induced ravens to swallow meat in tiny wire cages on the end of a string, pulling up the cages at intervals to inspect the processes of digestion, and showed that meat or other food in the case could be dissolved out by what was called an unorganised ferment in the gastric juice. For a time it was believed that there were both organised ferments within cells, responsible for such processes as alcoholic fermentation, and unorganised or soluble ferments which could exist outside of the cells and took part in processes such as gastric and intestinal digestion. In 1878 Kuhne named organised intracellular ferments 'enzymes', a word meaning 'in yeast'. When, in 1897, Buchner first prepared an extract of yeast cells which, although apparently free from organised cellular matter, could carry out all the processes of alcoholic fermentation, enzymes were shown to be within the grasp of chemical investigation.

In the early years of the present century the investigations of Harden and Young at the Lister Institute, in London, revealed the importance of substances formed by a combination between sugars and phosphoric acid in alcoholic fermentation, and later the work of Embden, Myerhof and others in Germany, and of Dorothy Needham in this country, showed striking similarities between the metabolic processes involved in alcoholic fermentation by yeast and in muscular contraction in frogs and mammals. More recently, the researches of Calvin in America, among others, has demonstrated remarkable similarities between certain pathways of carbohydrate breakdown in animals and those processes whereby carbohydrate is built up under the influence of light in the green plant.

In general, it may be said that the development of biochemistry over the past fifty years has laid bare what can be called a common ground plan of function with respect to all biological systems. It is indeed exciting to realise that the metabolic processes of micro-organisms, plants and animals (including higher animals) all have elements in common which would be unrecognisable without the activities of the biochemist.

Biochemistry in the Twentieth Century

The modern era of biochemistry in this country was ushered in under the influence of the late Sir Frederick Gowland Hopkins (1861–1947), the first professor of biochemistry in the University of Cambridge, who must be regarded as a most significant catalyst for the growth of the subject of biochemistry in general. It is said that in the 'eighties of the last century, the young Gowland Hopkins, then an analytical chemist, was considering taking up the study of the chemistry of biological processes, and asked an eminent chemist of that time what he thought about the idea. The recorded reply is, 'Chemistry of the living? That is the chemistry of protoplasm; that is super-chemistry; seek, my young friend, for other ambitions.' The pompousness of the reply is only equalled by its inaccuracy in the light of subsequent experience, and, fortunately, Hopkins was not put off by this reactionary attitude of his elders. By the application of analytical methods, with due attention to biological principles, he was soon able to show that what appeared to some to be super-chemistry was reducible to simpler terms. His early work on the crystallisation of proteins emphasised the fact that biological materials can be susceptible to processes of purification of a chemical and physical nature. He then turned his attention to the chemistry of muscular contraction, in association with the late Sir Walter Fletcher.

Fortunately, people like Hopkins and Fletcher were not put off by obscuring ideas about super-chemistry, or the beliefs of pessimists that biologically important processes were incapable of analysis by ordinary chemical means. They showed that when an isolated frog muscle is stimulated to contract in the absence of oxygen, lactic acid appears, but that the lactic acid disappears if oxygen is then admitted. The chemical analysis of lactic acid, and the physiologically significant state of the muscle which was analysed, were both points of great importance in this research, which had a most encouraging effect on those who had regarded the processes of muscular contraction as beyond biochemical analysis.

In 1906 Hopkins described experiments which he had carried out on the possibility of rearing and maintaining an animal on a completely artificial diet, the rat being a suitable laboratory object for this end. From the results of these experiments, he deduced the existence of what he called accessory food factors, present in a normal diet, and insignificant as a source of energy but, nevertheless, of greatest importance for the development and health of the animal. These researches were the birth of the general idea of vitamins. Since that time, as the result of the work of Hopkins and his colleagues, and of many others, it has been realised that

many of these vitamins enter into the constitution of catalytic systems of the cell, and there are converted into co-enzymes, and so assist the oxidation of foodstuffs. Such vitamins can be common to man and micro-organism. It was with work of this sort that Hopkins was able to direct the attention of biochemists to events which take place within the cell, and it is with these problems, above all, that biochemists have been concerned during the last fifty years.

The many investigations on vitamins which have taken place during the past forty years or so have allowed human nutrition to be treated on a rational basis never before possible. The successful application of laboratory principles on a nation-wide scale was demonstrated by the work of the Ministry of Food during the past war, with Sir Jack Drummond as the Chief Scientific Adviser. Sir Jack, himself a scientist of distinction, with the support of Lord Woolton as an inspired Minister of Food, regarded the war as an opportunity for attacking dietetic ignorance on scientific grounds and of changing the nutritional status of vast numbers of people whose condition had been the object of criticism before the war. The savage murder of Sir Jack and his family, in France, a few years ago, is still fresh in the minds of those who were inspired by him. The fact that the standard of health of the nation was so splendidly maintained during the dark war years, and after, gave emphatic support to the validity of the scientific basis of the policies followed by the Ministry of Food during the war years and afterwards.

Another aspect in which biochemical investigation has turned out to have a practical significance, wider than might be expected, lies in the development of B.A.L. by Sir Rudolph Peters and his colleagues at Oxford during the war. The discovery of this substance, based as it was on essentially biochemical ideas, arose from the need to provide an antidote for the war gas lewisite. But subsequently B.A.L. has turned out to have application as an antidote to a number of toxic substances, and has therefore found a place in the medical armamentarium. Truly, this is a most encouraging modern example of the beating of swords into ploughshares.

In the field of hormones, the internal secretions of glands, which have an immense physiological importance in the animal body, the researches during the past twenty-five years of Professor G. F. Marrian, now Professor at Edinburgh, on the oestrogens, the female sex hormones, and progesterone, have been outstanding. More recently, Dr. Sylvia Simpson and Dr. J. F. Tate of the Courtauld Institute of Biochemistry, Middlesex Hospital, London, succeeded in demonstrating the secretion of an important new hormone in the adrenal cortex. The isolation and chemical identification of this substance was subsequently carried out in conjunction with Professor T. Reichstein of Basel.

Dr. Frederick Sanger, of the Department of Biochemistry, University of Cambridge, has recently successfully completed an investigation which he began in 1945 and which was designed to reveal the structure of the hormone insulin, a substance which hundred of thousands of diabetic patients all over the world have to inject into themselves each day. Dr. Sanger's investigation has elucidated for the first time the complete structure of a protein, and the possibility that a substance as complex as insulin may now yield to synthesis in the laboratory is one that has the greatest theoretical and practical importance.

Biochemistry of Micro-organisms

The biochemistry of micro-organisms is a subject that has flourished in Great Britain during the past fifty years. The late Dr. Marjory Stephenson took up this subject in the early 1920's under the stimulus of Sir Frederick Gowland Hopkins, and her two pupils, Professor Donald Woods at Oxford, and Dr. Ernest Gale at Cambridge, are doing much to throw light on the biochemical mechanism of

bacteria and the means whereby antibacterial substances may exert their action. The Woods-Fildes hypothesis, put forward in 1940 jointly by Professor Woods and Sir Paul Fildes, suggests that chemotherapeutic agents may sometimes be chemical caricatures of vitamins which the microbe fails to distinguish from the substance it needs and so hopelessly clogs its metabolic machinery with a damaging foreign agent. This has done much to clarify fundamental ideas in the field of chemotherapy.

The researches which have been carried out in this country on the nature of ultrafiltrable viruses, particularly viruses which infect plants, by Dr. F. C. Bawden and Mr. N. W. Pirie at Rothamsted Experimental Station, and Dr. Kenneth Smith and Dr. Roy Markham at Cambridge, have again shown how the application of biochemical ideas and analytical methods to problems of biological complexity can yield results of fundamental significance.

Penicillin was discovered by Sir Alexander Fleming, a bacteriologist, and developed by Sir Howard Florey, a pathologist. Its isolation depended upon the co-operation of a biochemist, Dr. E. B. Chain. The subject of antibiotics of microbial origin, which is clearly of the greatest importance in the pharmaceutical industry, has been developed most successfully in the United States of America.

Since the war three Nobel prize winners in this country have been biochemists. In 1952 A. J. P. Martin and R. L. M. Synge shared the Nobel prize for chemistry for their investigations which led to the development of partition chromatography, a method which, in its application in all branches of scientific endeavour in which chemical methods can be used, has had a tremendous effect. In 1953 H. A. Krebs, now Professor of Biochemistry at Oxford, shared the Nobel prize for medicine with F. Lipmann of the United States. The investigations of Professor Krebs have been particularly concerned with the mechanisms involved in intermediary metabolism and the factors which determine their rate. His discovery of the tricarboxylic acid cycle has revealed a process of fundamental biochemical importance. The recent isolation and characterisation of vitamin B_{12} by a team led by Dr. E. Lester Smith of Glaxo Laboratories Ltd. is a tribute to the long-sightedness of those concerned in this industrial organisation.

Recent biochemical investigations have thrown light on the structure of the cell which is the basis of all living organisms. No longer can the cell be regarded as a bag of enzymes. It is now known to contain compartments, such as mitochondria and microsomes, which themselves have structure, and in which biochemists have shown great interest in recent years. In the address to the British Association in 1928 by Professor F. G. Donnan, to which I referred earlier, Professor Donnan pointed out that a living cell differs in a highly significant manner from, for instance, a motor-car engine, since if you deprive a motor-car of petrol or of oxygen, and the engine stops, the motor does not go to pieces. Whereas if you deprive a living cell of oxygen or of food, and it stops working, it at once begins to disintegrate, autolytic enzymes in the cell begin to hydrolyse and break up the dead cellular material. 'Why is this?' asked Professor Donnan. 'There must be something extraordinarily significant in the condition of the substances in the cell. There must exist some very curious inner structure where the protein molecules are marshalled arrayed as long mobile chains or columns.' In a strikingly gripping phrase Professor Donnan said, 'The harpies of death sleep in every unit of our living bodies, but, so long as life is there, their wings are bound and their devouring mouths closed'. The inner structure of the cell undoubtedly accounts for the situation which Professor Donnan described so strikingly. We know now, thanks largely to the investigations of Professor Christian de Duve and his colleagues at Louvain, in Belgium, that these harpies of death, these autolytic enzymes, exist largely in special containers in the living cell, which Professor de Duve calls 'lysosomes'.

Presumably, these potentially destructive enzymes are not able to bring about their action until the membrane surrounding the container, the lysosome, is

broken. The membrane is in fact the bond which binds the wings of Professor Donnan's harpies of death. The binding is presumably loosened by conditions of low oxygen tension, which could cause damage to cells and danger to the existence of the organism. A damaged cell which is allowed to live may be a potential danger to the whole body.

The picture that biochemistry now reveals of events within the cell is a fascinating one. Closely linked trains of enzymes, many with co-enzymes in common, hand on substrates, eliminate carbon dioxide from carboxylic acids, and catalyse many different types of intermolecular transfer or intramolecular change. They bring hydrogen and oxygen to union in the production of water under closely guarded conditions. The limiting factors in the activity of these closely locked systems, which will be rate-limiting, are probably few in number and include, as Lardy and Krebs have pointed out, the availability in the cell of such apparently simple substances as inorganic phosphate, or of more complex high-energy phosphate acceptors. How, for instance, hormones affect the rate of these intracellular processes is of great interest.

Biochemistry—The Present and the Future

It is clear that biochemistry is a healthy and vigorous offspring of the biological and physical sciences. Is it not surprising, Mr. Chairman, that the British Association has not yet instituted a section of biochemistry? Biochemical matters are from time to time discussed principally in the sections of chemistry and physiology, but also sometimes in zoology and botany, but these cannot give adequate time or interest to a subject which could fill more than a section in its own right. When one considers the magnitude of the number of the publications in the field of biochemistry, which now appear, it is indeed strange to me, as it is to many of my colleagues, that the British Association should not wish to hear more about discoveries in biochemistry than it possibly can without the institution of a section devoted to this subject.

Unfortunately in many ways, the demand in all walks of life for those who graduate in biochemistry is now so great that few biochemists become school teachers. Nevertheless, there is a growing awareness in schools of biochemistry as a university subject, and this has undoubtedly been fostered by the wide influence of Professor Ernest Baldwin's *Dynamic Aspects of Biochemistry* which, since its publication in 1947, has established itself as a standard and readable survey of the essentials of the subject. It is important that the boy or girl should have some idea, before he or she goes to the university, of the existence of biochemistry as a subject in itself which can appeal to lively minds. Perhaps, as my friend Professor Donald Woods has suggested, some enterprising person may bring out a set of materials and simple apparatus to enable youngsters to do experiments in biochemistry at home, in the way that for many years they have been able to investigate some of the mysteries of chemistry. The youngster is certainly less likely to blow himself up doing biochemical experiments in the home than he is doing experiments in chemistry.

In these times of technological development, biochemistry ought to contribute its share. There is clearly room for the development of what one might call biochemical engineering, the application of biochemical ideas on a large scale. The production of substances such as penicillin from micro-organisms is one example. Although on more than one occasion Sir Harold Hartley has emphasised the importance to the chemical engineering of the future of biochemical engineering, there still exists a reluctance on the part of some in industry to appreciate the potential value of biochemistry. Some say that there is nothing new in biochemical engineering, which according to them, is just the application of living catalysts in

place of, for instance, platinum, requiring no new techniques. The refutation of this view is clearly and concisely stated by Sir Harold in a recent article (*Trans. Instn. chem. Engrs., Lond.* 1955 **33,** 20–26) from which I may quote the following, 'I am quite unrepentant in claiming a special place for biochemical engineering as a postgraduate subject in which a background of the characteristics of the living cell and enzyme systems would be added to a training in the techniques of chemical engineering' (Hartley, loc. cit.). It is indeed to be hoped that those who are reluctant will in time follow Sir Harold's lead and that in industry, as in the universities, the ideas and methods of biochemistry will continue to grow with that vigour that has characterised its development during the past fifty years.

WORLD POPULATION GROWTH AND ITS REGULATION BY NATURAL MEANS[1]

by

DR. C. B. GOODHART

RECENT discussions on the future of humanity have tended to be rather discouraging, and there are plenty of eminent authorities, up and down the world, who are prophesying disaster. World population is now multiplying so fast that at the present rate it is bound eventually to outgrow its food supply, however much that can be increased, and then famine and disease will intervene to prevent further population growth, unless indeed the hydrogen bomb provides an effective and relatively humane alternative to more orthodox Malthusian agents. The only solution seems to be the immediate and universal application of a policy of deliberate family limitation, and few are so optimistic as to believe that this is either practicable or likely to be effective in time to save us from the crash.

It is important to remember, however, that population increase is primarily a biological phenomenon and that the arguments of Malthus, though mathematically sound, are based upon the assumption that Man has some specific and constant rate of reproduction which will be the same in the future as in the past, unless it is artificially altered. This is a biological assumption that remains to be proved, and this morning I want to consider whether there are any conceivable ways in which it could be falsified by natural as opposed to artificial means. Predictions in human demography are notoriously uncertain, and Malthus's disregard of possible increases in production proved him wrong during the last century, so we will do well to examine rather carefully any other assumptions upon which his theories rest.

In the first place we must recognise that Man has a rather low reproductive rate, compared with most other animals. A woman who has ten children is reckoned highly fertile, and with fifteen she approaches the phenomenal, and yet the domestic pig, of comparable size and on much the same diet, produces as many every year. In Man multiple births are rare, women are fecund for only about half their lives, conception may be inhibited during lactation, and more or less complete sterility is surprisingly common. These checks on fertility must be the result of natural selection, for if there had been any real overall selective advantage in higher fecundity it could easily have been evolved. Women are well adapted anatomically for nursing twins and the tendency to have them is certainly inherited so that their comparative rarity must mean that, owing probably to higher mortality, there can be no real selective advantage in multiple births even though, potentially, they could increase fertility. Is it possible that the mean fecundity of Man could be still further lowered by natural selection? If it could be halved during the next few generations that would probably solve our problems. At first sight this seems unlikely since we usually think of evolution as a slow process working through hundreds of generations, but there is an exception to this rule, where populations are already genetically heterogeneous for the characters involved and especially where the heterogeneity, or polymorphism, results from a balance of advantage between opposing genetic factors. Here, any change in selection pressure may alter the balance quite rapidly and lead to large changes in the composition of the population by altering the proportions in it of the two opposing types.

[1] Address delivered to Section D (Zoology) on September 5, 1956, at the Sheffield Meeting of the British Association.

In this country, for instance, we are polymorphic for hair colour and texture, dark, fair and red hair, curly and straight, are all common genetically inherited characters, and quite closely related races may have markedly different proportions of the various hair types, which, if they were subjected to selection, would not remain constant from one generation to the next. We are certainly also genetically heterogeneous for factors affecting stature, though here there are many genes involved and there is a graded series of different heights without any clear breaks as are found for the different hair types. The mean stature of the population seems to have increased by an inch or two since the Middle Ages, and this change may well be the result of natural selection if large people are more affected by food shortage and bad conditions of life than are small; improved conditions now allow more of the largest individuals to survive so that the average height of the population has increased. There is plenty of evidence that Man is also genetically heterogeneous for factors affecting fertility, and if the selective value of the different types were altered there would be a similar change in the mean fertility of the population, quite apart from any artificial restriction of family size. To take an extreme example, one type might have a mean family size of 10, and the other of 2 (though actually, as for stature, there will be a whole series of intermediates), so that a race with 90 per cent of the high fecundity type and 10 per cent of the low would have a mean family size of over 9, while in another, with the proportions reversed, it would be under 3. If for any reason these proportions were to be changed in the course of time as a result of natural selection the mean fertility would be greatly altered, and if the selection was strong an effect would be shown after only a few generations. In human beings, of course, fertility depends not only on natural fecundity but also on psychological and social factors which may limit the fertility of physiologically fecund individuals, but these other factors, like physiological fecundity, may well be at least partially inherited.

The present rate of increase in the numbers of Man is quite exceptional; the population of the world has certainly doubled and may have trebled itself in the last half-dozen generations, but the increases have not been the same in all races and classes of mankind. We rightly pay most attention to the teeming millions of Asia and Africa which have recently been multiplying at such an extraordinary rate, but during the same period many races have had stable or declining numbers, and some are heading towards extinction. The African Bushmen, Australian Aborigines, Red Indians and Eskimos should not be forgotten when the present mean rate of world population increase is extrapolated into the future. A century ago in Western Europe we had as high a rate of natural increase as any race before or since and yet it has been arrested and even reversed, admittedly partly by artificial means, in four generations, and the same could happen with other races as well.

The selective advantages of fecundity are obvious and they are particularly strong in dense populations living under unhygienic conditions and subject to acute epidemic disease and a high rate of infant mortality. Cholera and plague strike indiscriminately at rich and poor, strong and weak, alike, and where only a fraction of the children born can hope to live to rear families of their own, only the larger families will be represented in the next generation, irrespective of the quality of the individuals concerned, for small families are liable to be wiped out completely. Thus in these dense diseases-ridden communities selection for fecundity is relatively stronger than for most other qualities. In primitive races of pastoral nomads or hunters, however, who live widely separated under hygienic conditions, disease may be less important and the principal limiting factors will be periodical shortages of food. Here fecundity loses much of its selective advantage, compared with such other qualities as strength and intelligence, and may even become a liability. In a bad year an Eskimo might be able to find enough food to keep one or two children from starving, but if it had to be shared among ten all would be weakened by hunger

and die. It is just these primitive nomadic peoples that seem unable to recover their numbers after they have been afflicted with diseases introduced from outside. Individually they are often more virile and fitter in all repects but fecundity, compared with other races living a much less healthy life in dense centres of population, who seem able to replenish themselves almost immediately after the most disastrous epidemics. And yet we must remember that for 99 per cent of his history Man has lived as a nomadic hunter and food collector; the densely settled agricultural and urban communities characteristic of the last few millennia are really a very recent development. We cannot therefore assume that the high fecundity found in these dense and unhealthy aggregations of population is necessarily typical of the species; it might well have been evolved in response to these rather special conditions, and if selection pressures alter in the future, reproductive rates would alter too, and might revert to the lower levels characteristic of our remote nomadic ancestors, which would be more 'typical' of the species as a whole. Improvements in medicine, which would allow more children to reach maturity and so lessen the risk of extinction of lower fecundity lines, will then diminish the relative advantage of high fecundity, which will have been disproportionately increased when Man, at the dawn of history, abandoned his former more healthy nomadic way of life.

However, it is notorious that declining numbers are found not only in primitive peoples brought into contact with civilization, but also in many of the most advanced nations and classes, whose declining numbers certainly cannot be attributed to genetical selection by famine. It has been suggested that the conditions produced by civilization and a high standard of living may in themselves be unfavourable to fertility, and it is certainly true that the more or less stable population in North-Western Europe at the present time owes much to the introduction of artificial methods of family limitation which are only practicable in relatively advanced and prosperous communities. However, the universal rule of declining numbers in advanced civilizations dates back long before the discovery of artificial means of bringing it about, and we must not overlook the possibility that those qualities leading to success in Man may have become genetically correlated with relatively low fecundity, and there are some *a priori* arguments in support of such a view.

Under most conditions high fecundity has a clear selective advantage in itself quite apart from any other qualities with which it may be associated, but the less fecund lines will not survive unless they have other hereditary qualities of high survival value to offset the selective disadvantage of low fertility. It is obvious that a man with a dozen children, however ill-favoured, has a better chance of leaving grandchildren, as unpleasing but as fecund as their parents, than his neighbour with one plain daughter, but an exceptionally good-looking and intelligent young woman has little difficulty in finding a husband, even though she may lack brothers and sisters. Brains and Beauty, Virtue and Sex-appeal, Wealth and Social Position —that does not exhaust the list of attributes that may influence a man in the choice of his bride, before he considers her capacity to present him with a dozen children.

Francis Galton once showed that, in the pages of *Debrett*, wealth in woman was correlated with infertility. An heiress by definition comes of an infertile family, for otherwise there would be many to share her wealth, and many noble families have become extinct through an excessive love for heiresses, whose riches were matched by their infertility. We may now put forward another rule, that not only wealth but also nubility in women is likely to become associated with infecundity. Attractive girls will usually marry and the fecund will have large families while the less fecund will do their best and will certainly leave some descendants in future generations. Unattractive but highly fecund girls will be less likely to marry, but those that do will have plenty of children so that, as a group, the unattractive but fecund will also leave descendants. However, the group that is both unattractive and infecund will

be at a double disadvantage and so will tend to be under-represented in future generations. Consequently in each generation, owing to the elimination of this last group, we would expect to find that the mean fertility of nubile and attractive mothers should be below that of the less attractive. This proposition cannot easily be proved, there seems to have been a regrettable lack of research on nubility in women, but as an illustration of what is meant we may consider the breeding record of King Louis XV of France and Mme. de Pompadour, the subject of a recent biography by Miss Nancy Mitford. The King took as his wife the Princess Marie Leczinska of Poland, aged about 16 years and probably deliberately selected for dynastic reasons on account of the splendid record of fertility in her family. She developed into a plain, healthy and rather dull woman who enjoyed the King's not undivided attentions until, at the age of 27, her reproductive career ended with ten children of whom six survived to maturity. Mme. de Pompadour then took over the far from nominal duties of *maîtresse en titre*, which she performed to general satisfaction for nearly twenty years. She was aged 23 when she met the King and had had one child who died young, but though she is said very much to have wanted children by the King, and had several miscarriages, she had no further living children; the King himself left plenty of evidence elsewhere of his own continued fecundity. Mme. de Pompadour, who was considered one of the most attractive, intelligent and accomplished women of her time, came of a bourgeois family that had risen in the world to a position of considerable affluence, and her own mother, married at an early age and renowned more for her beauty than her virtue, herself had only two children. The contrast in fertility between the nubile mistress and the unattractive Queen is striking.

Using similar arguments we would expect that most other human characteristics leading to success in life will become genetically associated with lower fecundity, quite apart from the fact that in more advanced communities low fertility in itself usually results in a higher standard of living.

We know that in animals and plants genetic characters are usually only maintained at the highest level if they are subject to continuous selection, and that there is a loss of fitness as soon as selection pressure is relaxed; this process has been called 'genetical erosion' by Prof. Harland. There is probably an example of this effect in Man with milk yield. A considerable number of civilised women are unable to feed their own babies, although in more primitive races mothers seldom have this difficulty, so long as they are adequately fed. The easier life of civilised women is unlikely to be the direct cause of their inability to produce sufficient milk but, since artificial feeding is now perfectly satisfactory, selection against low milk yield has ceased. In less advanced peoples, on the other hand, the only children to survive infancy are those whose mothers did have an adequate milk flow. In domestic cows milk yield has been greatly increased in a few generations by deliberate selection, and in civilised Man the reverse seems to have happened, also in quite a short time, as soon as selection was relaxed. So also, if selection for the highest fecundity is relaxed, we would expect to find a fall in the average fecundity of the population, as is in fact seen in advanced races with low mortality.

We have suggested that, in Man, the more desirable qualities are likely to become genetically associated with lower fecundity, and that there is good evidence that Man is genetically heterogeneous for factors affecting fertility. It is likely that this heterogeneity will be maintained by a balance of advantage between higher fecundity on the one hand and other qualities of high survival value associated with lower fecundity on the other. It is indeed hard to see how the observed heterogeneity could exist at all unless there was this compensating factor, for without it the lines of lower fecundity could never survive in the face of natural selection. Any equilibrium of this type will be an unstable one, and will be disturbed if the mortality rate in early life is altered; if it is lowered the *relative* advantage of high fecundity

will be diminished, and so we would expect the lower fertility lines to show a proportionate increase.

All this, of course, is rather speculative and, since experiments are impossible, really conclusive evidence one way or the other is very difficult to obtain. It may however be instructive to consider the population problems of Ireland, which do suggest that selection against fecundity may have had important results over quite a short period. Before 1750 the native Irish lived in conditions of the direst poverty, and must have had a high infant mortality with correspondingly strong selection in favour of fecundity. The introduction of the potato then raised the standard of living and there was an extraordinary increase in the population, similar to but greater than that occurring at the same time in England and elsewhere. In Ireland, however, the increased population supported itself almost exclusively on this one food crop until in the 1840's, in the words of H. G. Wells, 'the weary potato gave way under its burden' and was blighted by disease, with the inevitable result of a disastrous famine followed by disease and emigration. In the normal course the formerly highly fertile population should have replenished itself rapidly and resumed its growth with only a slight check, but this did not happen and the population of Ireland has continued to decline until now it is barely half of what it was in 1840, though most neighbouring countries have doubled their populations during the same period. A probable explanation of this unexpected decline is that since the Famine there has been rather strong selection against large families, though artificial restriction of numbers has probably been less important in Ireland than elsewhere.

In the first place, large families are likely to have been worse affected by the Famine than smaller ones; where there were numerous children to share the little food available all would be weakened by starvation and may have died. Secondly, and even more important, emigration will have been selective. An only son who has hopes of inheriting the family farm, however impoverished, will not readily abandon it, but if it is to be shared among half a dozen brothers most of them will be inclined to seek their fortunes elsewhere when times are bad. By 1850 the population of Ireland would have lost most of its more fecund members leaving the task of replacement to the genetically less fecund who remained. For various special reasons this process is likely to have been continued. A girl's chances of marriage depended largely on the size of her dowry, and that was inversely proportional to the number of sisters who had to share what could be spared. The peasant economy required that adult children should remain on the family farm as unpaid workers, and this tended to advance the age of marriage and so to reduce the number of children born. That in itself was an important though not a genetical factor in limiting population, but it is also likely that the more enterprising and virile young men and the more highly sexed girls will have rebelled against these restrictions and left for abroad. The present low fertility in Ireland seems to be due largely to late marriage and failure to marry rather than to low fertility in those women who do marry young, and it is said that many people in Ireland nowadays are 'not the marrying type'. Their infecundity may be psychological rather than physiological, but it is none the less real, and psychological characteristics can be inherited just like anything else; their preponderance in the population could well be the result of selective emigration of those that *were* 'the marrying type'. This process, once started, will continue, for a girl who wishes to marry but lives among a lot of confirmed bachelors will be all the more likely to try her luck elsewhere. Although economic impediments may be given as the reason for late marriages, they are unlikely to be its primary cause, for a much lower standard of life than that at present enjoyed in Ireland does not prevent marriage and procreation in many other countries, and it was not effective in Ireland before the emigrations. Nor is the influence of the Church to be neglected, the call to the convent or the priesthood will no doubt be

all the stronger if there is little in the way of worldly wealth to be left behind, and it would not be surprising to find that the mean number of brothers and sisters to each priest and nun in Ireland was significantly higher than for married people of the same age groups.

There is another important argument in favour of our suggestion that the selective disadvantage of lower fecundity is compensated by other characters of high survival value associated with it, and that is in the inheritance of intelligence. It is well known that in this country at the present time really large families of ten or so children are often of low quality and below average in intelligence, and it has been suggested that since the less intelligent seem to be the most prolific this means that the average level of intelligence of the population will be falling, and that 'civilisation is rotting at the core'. In point of fact the only really large-scale direct observations that have been made, on the I.Q. of school children in Scotland in 1932 compared with 1947, failed to show any sign at all of the expected fall in mean intelligence. This has been considered a very puzzling and unexpected result, but it is puzzling only on the assumption that the fact that the largest families are to be found among less intelligent people means that as a group the less intelligent will leave proportionately more descendants in each generation. This is by no means self-evident for, quite apart from possible higher mortality in large families of low quality, the data refer only to the low intelligence of the largest families but give no information about the mean family size of the less intelligent as a group. If intelligent people, though fewer of them have really large families, more often marry and have small families than do the less intelligent, they may well leave as a group as many descendants as the less intelligent, of whom a few have the largest families but a higher proportion leave no children at all. If this really is what happens the mean level of intelligence of the population should remain constant and the Scottish results are puzzling no longer.

We might be able to get direct evidence of differential survival in high and low fertility lines in populations for which statistics are available of the distribution of family size two or three generations back. From these we could derive a figure for the number of great-grandchildren to be expected by women who had had families of various different sizes, which could be compared with the number of maternal great aunts and uncles actually possessed by a sample of children from the latest generation. If they were below the expected number this would confirm our hypothesis that relative infertility a few generations ago had been compensated for by better survival and reproduction among the descendants of the infertile families.

To sum up, we have suggested that human populations are genetically heterogeneous, or polymorphic, for factors affecting fertility, and that this heterogeneity is maintained by a balance of selective advantage of high fecundity on the one hand, and other factors of high survival value associated with lower fertility on the other. These other factors are seen to be mainly such qualities as intelligence and nubility, which by increasing the chances of success in life and of marriage should compensate for lower fertility, with the further possibility that better health and lower mortality may also be involved. In addition, the lower fertility lines may have a larger proportion of small families with fewer individuals leaving no children at all, so that the difference in mean fertility will be less than is suggested by a consideration only of the largest families in each group. An objection may be raised here, that there is little reliable evidence of this hypothetical association of desirable qualities with lower fecundity, and that to outweigh the very real disadvantage of low fertility the association should be too obvious to be overlooked. To this I would reply by asking another question. We know that more or less complete sterility is surprisingly common, affecting perhaps 10 per cent of married couples, besides those people who never intend to marry and who must be considered psychologically infecund. Such infecundity is generally intrinsic and not due to injury or disease, and

it is therefore likely to be at least partly conditioned by inherited congenital factors. Since selection against infecundity is absolute, and stronger than for many rare and harmful though not actually lethal genes, how could any genes responsible for it possibly occur at anything like their present level in the population, unless the lines that tend to produce infecund individuals had some important compensating advantage as compared with other lines in which the incidence of infecundity was lower?

If this genetic heterogeneity is maintained as we have suggested by a balance of advantage between high and low fecundity, the balance will be an unstable one, and the lines of high fecundity, but otherwise of lower quality, will be especially favoured in dense populations where mortality from disease is high and indiscriminate, and where small families may be entirely wiped out by disease before benefiting from their presumed greater intelligence or nubility. Such conditions have been experienced by Man only during the past few thousand years, so that in many parts of the world at present the mean fecundity of the population is likely to be disproportionately high, compared with our more remote ancestors who lived a healthier life in which strength and intelligence, rather than mere fecundity, had a higher survival value. Now that disease is being mastered and early mortality is becoming negligible, even though we continue to live in dense communities, families of lower fertility, but otherwise of good quality, will survive so that they can take full advantage of these better qualities in competition, and the balance of advantage should shift away from the lines of highest fecundity but otherwise of lower quality. It is to be expected, therefore, that at first when new medical techniques are introduced into formerly disease-ridden and fecund populations there should be a rapid rise in numbers, but as the less fecund lines begin to benefit from the new situation, and increase, the mean fertility should fall and the population should taper off to a new position of equilibrium at a much higher level of numbers and, perhaps, with a higher level of intelligence and other desirable qualities.

Sir Charles Darwin, in his stimulating and provocative book *The Next Million Years*, adopts the Malthusian argument that, in the long run, human populations must always be limited by food supplies, and there will always, or at any rate usually, be a large 'starving margin', and he concludes with the challenge that 'Anyone who disagrees with my forecast must try to get beyond a vague optimism. . . . In particular he must find a really solid reason which shows how the threat of over-population will be avoided. . . . or else he will find that his imagination has gone so far out of the realms of reality that it contradicts the physical or the biological laws of nature.'

I have tried to show that there may be, if not really solid reasons, at least plausible arguments not inconsistent with the biological laws of nature on the basis of which we may question the fundamental Malthusian assumption that human fecundity has some constant and rather high mean value which could only be altered by artificial means. It is at least conceivably possible that prosperity may provide its own solution to the problem by being the cause of a natural lowering of the rate of increase of the population. Whether my arguments have carried conviction, or whether we continue to believe in the essential correctness of Malthus's analysis, our actions at least will remain the same. No one seriously believes that we can or should deliberately limit increases in world food supplies, nor that we should withhold medical discoveries from over-populated regions, however much many may fear that the benefits they bring will in the end prove illusory. Nor does anyone doubt that these benefits will be the cause of an immediate and in some parts of the world, at least, an undesirable increase in the present population, which should be restricted by all legitimate means, however much opinions may differ as to what means are legitimate. All I am suggesting is that it is just possible that what we are in any event bound to do may, if we do it in time, not lead our descendants inevitably to disaster.

TASTE, APPETITE, AND THE SELECTION OF FOOD

SECTION I (Physiology) devoted the morning of Thursday, August 30, 1956, at the Sheffield Meeting of the British Association, to a discussion of taste, appetite, and the selection of food. Professor Y. Zotterman (University of Stockholm) introduced the session with a paper on 'Electrophysiological investigations on the functions of gustatory nerve fibres'. He was followed by Dr. J. G. Gordon (Rowett Research Institute), who, in a paper entitled 'Palatability in relation to physiological needs', discussed evidence derived from food-choice experiments. Dr. R. Harper (University of Leeds) then, dealt with 'Psychological aspects of food acceptance'. The session ended with a contribution from Dr. H. N. Munro (University of Glasgow) on 'Time factors in nutrition' which reviewed the effects on the body of the time at which nutrients are consumed in relation to one another.

Professor Zotterman's paper, which is published below, is followed by abridged versions of the other contributions.

ELECTROPHYSIOLOGICAL INVESTIGATIONS OF THE FUNCTIONS OF GUSTATORY NERVE FIBRES

By Professor Yngve Zotterman

The old conception of four classes of taste, viz. sweet, sour, bitter, and salt, which we have inherited from the psycho-physics of the previous century appears to most people as simple and comprehensible, and so much in agreement with general experience that very few people have been interested in the basic problems of taste until recent advances in electrophysiological technique created new means of a direct study of the activity within the very taste nerve fibres themselves.

One would be inclined to believe that such a comparatively simple sense as taste would be easy to elucidate, at least in its peripheral mechanism. This, however, has not proved to be so for a diversity of reasons. First, all the taste nerve fibres are relatively small fibres (as I was able to demonstrate as early as 1935) and thus difficult to handle and to record from. I found in those days that the cat possessed taste fibres which responded to salt, bitter and acid solutions but not to sweet-tasting solutions. An American colleague, Prof. Pfaffmann, in Providence, Rhode Island, who before the last world war worked with Lord Adrian in Cambridge, has confirmed this, but, still more important, he showed that acid solutions of a pH below 2·5 stimulated all kinds of taste nerve endings. Thus a complication was added to our concept of taste in that it became necessary to speak of salt–acid fibres—i.e. fibres that responded to the application of salt as well as acid on the tongue. But besides this he also found fibres that reacted only to acids. The salty taste should thus be discriminated from the acid taste only by the absence of impulses in the specific acid taste fibres.

Then seven years ago I observed that the frog possessed taste fibres which responded to the application of pure water on the tongue. I first believed that these water fibres served a particular purpose in the regulation of the water intake in these animals living mostly in fresh water. This finding, however, raised the old question debated by psychologists for half a century, whether mammals, including man, are equipped with specific taste organs for water. In Stockholm the professor of psychology David Katz had long keenly maintained that this must be the case.

In examinations he often put the question, 'What is the taste of water?' The correct answer was: 'wet'.

The suspicion that even warm-blooded animals might possess specific water receptors was strengthened substantially by a recent series of taste tests made by Liljestrand on himself. Confirming earlier investigations in this field, he found that the threshold value for NaCl solutions lay between 0·009 and 0·002 M, i.e. about 0·05–0·01 per cent NaCl. It was just between the concentrations where I had found that the specific water taste fibres began to respond. But at that concentration the NaCl does not taste salty. Nevertheless, it is possible with 100 per cent certainty to differentiate between distilled water and the tap water of Stockholm City when you have boiled them both and cooled them down again to the same temperature.

Animal experiments have confirmed beyond doubt that mammals can detect water with their taste buds. Leading off the action potentials from the entire chorda tympani nerve in the cat, dog and pig, Liljestrand and I in 1954 were able to demonstrate that these animals possessed taste fibres the endings of which responded to the application of water on the tongue. By splitting up the nerve in fine strands we were able to find preparations which responded to the application of water on the tongue but not to 0·5 M NaCl solutions, and also strands which responded to 0·5 M NaCl but not to water. We could therefore state that these animals obviously possessed specific taste nerve endings which responded to water containing no electrolytes or only very small amounts.

Skramlik (1926) reported that, in humans, salt solutions below 0·03 M taste sweet and that 'saltiness' appears only with concentrations above 0·03 M. Although it may be dangerous to generalise from cat receptor-threshold to human sensation, it is nevertheless intriguing that a salty taste is evoked in humans only when a saline concentration is reached where the cat 'water' fibres are completely depressed. This may indicate that the salty sensation evoked by relatively low salt concentrations is due to the absence of activity in 'water' fibres.

Discrimination within an entire stimulus range by two distinct fibre types with frequency maxima at opposite ends of the range is similar to the way the thermoreception problem has been solved (see Zotterman, 1953). The warm fibres of the thermoceptive system can be considered analogous to the 'salt' taste fibres in that both respond only in the relatively high intensity region of their respective stimulus range. The 'water' fibre plays a role similar to the cold fibre by responding in the low-intensity region. Thus, for at least two exteroceptive systems, adequate discrimination within the entire physiologically significant stimulus range is beyond the capability of a single receptor; the general solution of employing two distinct fibre types which respond in opposite regions of the sensitive range has been evolved as a solution for this problem.

In the previous investigations the fibres responding to water were differentiated from those responding to hypertonic salt solutions though both kinds responded to acids. It is known from Pfaffmann's work (1941) that many mammalian taste fibres respond to more than one chemical stimulus, and it was felt that the response spectrum of the mammalian 'water' fibres should be more rigidly defined. For that purpose Cohen, Hagiwara and I (1955) undertook an investigation in which the response of single fibres from the chorda tympani of the cat was thoroughly analysed. The result of this study is summarised in Table I.

From this table it will be seen that most 'water' fibres were found to be stimulated not only by water but also, besides acids, by quinine. In later experiments, however, I have obtained single-fibre preparations which responded to water and acids but not to quinine. It is apparent from these investigations on single fibres that even so-called primary taste sensations are built up from a composite input pattern of several taste fibre types. In the cat there are only two substances which

stimulate one kind of fibre only, i.e. NaCl and water; all other sapid solutions stimulate more than one kind of taste fibre, and this is in full accordance with our subjective experience. NaCl solutions are the only salt solutions which elicit a real pure salty taste.

Even with stimuli which activate only one fibre respectively, such as water and NaCl, the impulse pattern must still be considered important in that lack of response in the other taste fibres is necessary for the arousal of a water or salt sensation. It appears that the activity of the two-fibre types which respond only to one stimulus, i.e. the 'quinine' fibre and 'acid' fibre, dominates the 'water' fibre activity centrally during simultaneous stimulation. Most likely the same holds for the 'sweet' fibres in the dog and pig, etc. Thus a bitter taste or a sweet taste results when 'quinine' and 'sweet' fibres respectively respond simultaneously with 'water' fibres. A water taste is aroused when the 'water' fibres alone are stimulated.

In recent years Pfaffmann and Beidler in U.S.A., using electrophysiological methods, have noticed very great species differences in the response of the taste fibres of the chorda tympani. Thus they have both observed the great difference between the rat and the cat in respect to their response to weak NaCl solutions as well as to quinine.

TABLE I

Stimulus	Fibre type response				Sensation evoked
	'Water' fibre	'Salt' fibre	'Acid' fibre	'Quinine' fibre	
H_2O (salt $< 0{\cdot}03$ M)	+	0	0	0	→ Water
NaCl (0·5 M)	0	+	0	0	→ Salt
HCL (pH 2·5)	+	+	+	0	→ Sour
Quinine	+	0	0	+	→ Bitter

Due to these great species differences I recently extended my study of the water taste to the pig, the rabbit and the white rat. The pig produced a response to water very similar to that of the cat, and the rabbit also demonstrated a definite response to water; the response in this latter animal was delayed a few seconds but was of lasting character.

In contrast to all other mammals tested so far, the rat did not show any positive response to water. The application of water on the rat's tongue caused only an immediate decrease of the spontaneous activity which could be reduced to nil, to return slowly in ten seconds after the cessation of the water flow. After a water rinse, even as weak a solution as 0·003 M NaCl caused an obvious and persisting response in this animal.

The high level of spontaneous activity observed in the rat's chorda tympani is most likely an expression of the high sensitivity of its taste receptors to NaCl. The chloride ion concentration of the rat's saliva seems to be a constant stimulus to the salt receptors. In the cat, dog, rabbit and pig, on the other hand, the receptors adapt quickly to a NaCl solutions of that concentration.

The very high sensitivity of the rat to weak NaCl solutions found in these experiments accords with the result of Pfaffmann's behaviouristic experiments on

rats and can in itself explain the high discriminating power of these animals. There is as yet no information in regard to salt-discrimination in the cat, dog or pig. If these animals were entirely dependent upon their salt fibres their discrimination of salty solution should be rather poor. But these species possess water fibres which may serve very well in the discrimination between water and weak salty solutions.

As concerns our own discrimination in this respect, we have previously suggested that the water fibres would provide further means for the discrimination. But lacking direct proof of the existence of any water fibres in man, it would be premature to discuss whether our own discrimination is due to highly sensitive salt receptors alone as in the rat, or to a dual system of salt and water fibres the activity of which is contrasted against each other because of their reciprocal mode of stimulation.

Now you may ask what effect these findings have on our general conception of taste. The answer is first of all that the new observations emphasise the importance of the afferent impulse pattern. It also may explain the phenomenon that electrical stimulation of the chorda tympani in man (during ear operations) in most cases is not reported as giving rise to a taste sensation. Most likely because all taste fibres are stimulated and thus an impulse pattern is produced which was never experienced before.

Further, we urgently need all this information about inflowing taste impulses from the tongue in order to study the function of the cerebral gustatory mechanism. Dr. Landgren and I are now trying to study this central mechanism by using microelectrodes enabling us to record the activity of single nerve cells in the cortex. We have succeeded in five cases in finding cells in the cortex which respond to the application of tasty solutions on the tongue. This has been done on the cat. Most of these cortical taste cells responded to many stimuli—to salt, bitter and acid solutions, and water too, but not to sweet tastes and not to 0·1 M NaCl solution. These cells were thus not specific central receivers but are just receiving the modality 'taste'. They did not respond to touch or temperature. Thus their activity probably means nothing more to our subjective sensation than just 'taste' in contrast to touch, warm or cold. These cells are found in the cortex just behind the orbita in the same field as that for the touch and temperature fibres of the tongue. The cat does not possess any specific primary cortical region for taste corresponding to the visual and auditory fields. The primary cortical area of taste is the same as for all other senses in the tongue.

It is no doubt true that if we accept the implications of these new findings we must recognise the great difficulties in interpreting directly the results of our introspective analysis of sensations in terms of the physiological analysis of the afferent nervous mechanisms. But new pathways of advance are opening before us; our methods of investigating the nervous system now allow us to record cortical events within the cortical elements themselves. It is indeed a very exciting time for us neurophysiologists. We feel we are on the threshold of new discoveries which may at last allow us to peep into the inner temple of knowledge, the understanding of the physical basis of mind.

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PALATABILITY IN RELATION TO PHYSIOLOGICAL NEEDS

By Dr. J. G. Gordon

The term 'palatability' should not be confused with the palate nor with the sense of taste, since the palate lacks taste organs. Palatability should be broadly defined, to cover its use throughout the field of animal nutrition, as 'the sum of the factors which operate to determine whether and to what degree a food is attractive to an animal'. (5)

Food of itself is neither palatable nor unpalatable. Palatability depends on the relationship between the food on the one hand and the animal on the other. The factors involved operate through the senses of touch, smell, taste and vision; these may vary according to such factors as: type of animal, acuity of senses, hunger, appetite, and psychic factors. The latter include the quantity of food offered, dietary history, social facilitation and learning.

To examine the effect of dietary history, Tribe and Gordon (5) offered a group of twelve rats the choice between two diets, A and B; both were nutritionally adequate, but they were quite different in colour, texture, smell and taste. Over a two-day period nine animals preferred diet A and the remaining three preferred B. For fifty-five days all the rats were fed only on the diet for which they had shown a preference and then the same choice of diets was reintroduced. In each case the previously unattractive diet was preferred, i.e. the relative palatabilities had changed.

The question arises as to whether palatability reflects bodily needs. If an animal has a dietary deficiency and prefers a food containing the substance it lacks, but which is less attractive to it in other circumstances, then this change in palatability may be brought about either by a change in the activity of the senses or by a change in some other unknown dominant factor. Taste may be important in relation to the sugar content of the blood and may vary in relation to it.

We tested this using two adult sheep (5). There was no relationship between blood-glucose level and the choice of different glucose solutions. One sheep consistently chose weak and the other strong solutions despite attempts to decrease and increase blood-glucose levels.

Correct self-selection of diet would be an example of palatability satisfying nutritional needs, acting through either 'appetite instinct' or learning. Gordon and Tribe (1) housed eight adult North Country Cheviot ewes in roomy individual pens and allowed them to choose their own diet from a number of components. They were mated six weeks after introduction to the system and were kept on it until they lambed. A diet low in protein but otherwise adequate was consistently selected and the sheep continued to make the same choice throughout pregnancy. Only where the lambs born were small were the ewes at all normal, and the small lambs of one of these were too weak to stand and could not be saved; 62·5 per cent of the lambs did not survive.

In this experiment there was no evident relationship between the palatability of the foods offered and the animals' needs. They consumed carbohydrate to excess but the protein supplement remained unpalatable.

In an experiment with rats (5) we used eleven young females which were allowed to choose *ad lib.* from the separate constituents of an adequate diet. After twelve days one rat died because it would not eat, and after thirty-one days each of the remainder was mated. Eight became pregnant and sixty-eight young were born. By weaning, thirty-four of these had been eaten by their mothers. Nine of the surviving young died when placed on the self-selection system after weaning. This was repeated later, (4) when Tribe found that, at around 100 g. body-weight, growing rats could learn to select reasonably well. On the other hand, both young and adult rats failed to do so.

In 1933 Harris *et al.* (3) found that B-deficient rats selected B-adequate food as the result of learning to associate the beneficial effects of the vitamin B complex with a flavour. Unless deficient, they failed to do this. By means of a wrong cue they could be made to select a deficient diet. Here, through learning, the palatability of the diets altered in relation to needs.

Later, Tribe and Gordon (6) showed that rats could readily select for pure B-vitamins in diets which were indistinguishable to a test group of twelve normal humans. Both deficient and non-deficient rats could do this. Once again palatability was related to nutritional needs, apparently through appetite instinct since there seemed to be no learning involved. Rats lacking a sense of smell were also able to select correctly, with no impairment of the power to do so (7). The ability to choose correctly extended even to separate parts of the B complex (8). The diets were selected on the basis of the number of B components they contained. Thus palatability was again related to bodily needs, though the mechanism is obscure.

Gordon, Tribe and Graham (2) have found that phosphorus-deficient cattle and sheep failed to consume adequate amounts of readily available phosphorus when a choice of mineral supplements containing and lacking phosphorus was made available at all times on phosphorus-deficient grazings on the Isle of Skye. There was a change in the palatability of debris on the grazings caused by the animals' state of aphosphorosis. Bones and even carcases were chewed by them. Yet this change in palatability was not due to a guided seeking after phosphorus, but was apparently random, as it did not cause the animals to consume the best, the most accessible and probably the least abnormal source of phosphorus on the grazings.

From such evidence it emerges that palatability *per se* is not to be relied upon too greatly. *X* may be palatable taken in conjunction with *Y* and be unpalatable alone, and it may be very palatable to a ravenous animal or to an animal with a different history, and yet none of these factors need reflect its physiological value. Is it true to say that 'a little of what you fancy does you good'? The answer seems to be that it may do you good because you fancy it, but it is doubtful whether you fancy it because it does you good.

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PSYCHOLOGICAL ASPECTS OF FOOD ACCEPTANCE

By Dr. Roland Harper

Psychological aspects of food acceptance are many and varied. They range from the problems of changing food habits to the consideration of what underlies the development of those habits; from the direct role of the senses in food acceptance to the more complex problems of likes and dislikes; from food acceptance in man to comparable aspects of animal psychology. Confining attention to food acceptance in man, two specifically psychological aspects are considered here. These concern standardised forms of description and the systematic study of likes and dislikes. Apart from the act of naming, at least three distinct sets of information are required to make a comprehensive statement about a particular food. These are:

1. Description in terms of such sensory characteristics as sweetness, sourness, astringency, hardness, stickiness, coolness and general appearance. These are

particularly psychological in the sense that they provide information derived essentially from the use of *man as an instrument*.

2. The evaluation of foods in essentially non-human terms which include information derived from physical, chemical and biochemical analysis. This information is of psychological interest primarily in so far as it provides important outside points of reference about which there can be general agreement.
3. Systematic information about (human) likes and dislikes and about general aspects of choice and preference. This places considerable emphasis upon individual differences and upon a broadly clinical approach.

One of the roots of modern psychology lies in the psychophysiological studies of the human senses dating back to the middle of the nineteenth century. At the same time a number of psychologists have a close affinity with the contemporary neurophysiological approach to sensory phenomena. However, the majority of psychologists are much more concerned with the functioning of the intact human organism than with what is going on inside. Perhaps it would be more correct to say that the primary difference in outlook between the physiologist and the psychologist is one of level of organisation with which the respective disciplines are concerned. This is thrown into sharp relief by comparing the electrophysiological approach to the sense of taste, which Professor Zotterman has outlined earlier in this Symposium, with the present approach which deliberately takes everyday experience and behaviour as its starting-point.[1]

A systematic appraisal of foods by sensory methods poses its own special problems. What is ultimately appropriate for coffee in the way of methods and techniques is likely to be quite inappropriate for white fish. The basic problem involved in the effective use of sensory appraisal lies primarily in the standardisation of techniques. Restricting attention solely to (tongue) taste, Beebe-Center (1) has developed a series of cross-matched reference standards covering each of the four traditionally primary tastes. The system consists of nine separate solutions of each of the four substances, sucrose, sodium chloride, tartaric acid and quinine sulphate, in psychologically equal steps ranging from 'very weak' to 'very strong'. The task of the taster is to find the point on each of the scales corresponding to the appropriate level of each of the component tastes in the sample being appraised. The approach has much in common with well-established measurement techniques and breaks away from the long-established custom of attempting to explain sensory phenomena at normal levels in terms drawn solely from information about just detectable (threshold) levels of stimulation. A similar approach to that outlined has already been applied by Franklin Dove (2) to certain problems of food technology bordering upon hospital feeding.

The extension of systematic investigation to the study of likes and dislikes raises a number of very different problems. Beebe-Center (3) has given a co-ordinated account of an experimental approach to the problems involved. This work includes a résumé of data on the relative preferences for different concentrations of the usual taste stimuli. Over and above any general consensus of opinion, individual differences were so pronounced as to justify referring to the two extremes as 'types' who showed a predominant liking (or disliking) for salt, sour and bitter.

A different line of approach is to seek information about people's likes and dislikes by means of appropriately designed questionnaires. Illustrating this approach by information about the taste for vegetables, two major points seem to emerge from the literature. There seems to exist a group of 'problem vegetables' in the sense that they are disliked by about 40 per cent of the persons who have tried

[1] At least one point of immediate agreement has emerged from these two widely different approaches. Both have led to the rejection of the view that the subdivision of taste into the four qualities, sweet, salt, sour and bitter, can be regarded as an analysis into genuine 'primary tastes'.

them. A small-scale pilot survey suggests that in this country the group would probably include hot beetroot, parsnips and spinach. General agreement is most likely to be reached only in connection with what people like and not what they dislike, and even the most popular item may be strongly disliked by someone.

It is clear that a wide range of individual, regional and national differences in food acceptance could be listed. Whereas certain limited facts of food acceptance can be fitted into a physiological framework, in the present state of knowledge many others obviously cannot. More often than not the facts of individual differences in food acceptance have to be accepted as source data rather than explained in other terms. The exceptions will normally involve a clinical approach which inevitably places as much emphasis upon psychological factors as upon the physiological. However, the illustrations which have been given of certain contemporary psychological approaches to the many problems of food acceptance should make it clear that the term 'psychological' refers to data which are inherently capable of systematisation.

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TIME FACTORS IN NUTRITION

By Dr. H. N. Munro

In a discussion on taste and appetite, it is pertinent to consider whether the way in which a subject distributes his daily diet among individual meals has any nutritional importance. In other words, do we derive greater benefit from the diet if certain nutrients are consumed together rather than at separate meals? In certain instances it can be shown that such time factors do exist in nutrition. We shall now consider a few examples of time factors which influence protein utilisation.

It will be remembered that protein utilisation begins with digestion. In the digestive tract, the dietary proteins are broken down to their constituent units (amino acids). These are then absorbed into the bloodstream, which transports them to various parts of the body, where they are used to replenish the tissue proteins. This process of building tissue proteins involves a source of energy, provided by the carbohydrate and fat of the diet.

We may now consider whether there are any nutritional time factors involved in these steps. In the first place, is it essential that all the amino acids used for tissue protein formation should arrive at the tissues simultaneously? This problem first came to the attention of nutritionists when predigested proteins were being used to feed patients who were unable to take food by mouth. In order to by-pass the digestive tract, these protein digests are injected directly into the bloodstream. The process of preparing the digest leads to the destruction of one of the amino acids, and this has subsequently to be added to the digest in order to make it nutritionally complete again. It has been found that, when the missing amino acid is injected separately from the rest of the digest, the body fails to make use of the protein digest. In other words, all the amino acids needed for tissue protein formation must be made available to the tissues at the same time.

The same principle can be seen at work in another series of studies in which rats were fed bread and cheese as their sources of dietary protein. The dietary protein was better utilised when the bread and cheese were eaten at the same time than when the same amounts of bread and of cheese were fed on alternate days. This occurs because the protein of bread contains rather small amounts of certain

amino acids and the presence of cheese protein in the same meal compensates for these deficiencies. This advantage is lost when the amino acids from these two sources of protein are not made available to the body at the same time.

A second point at which we might expect a time factor to operate is in the provision of energy for tissue protein formation. In other words, will a large amount of carbohydrate and fat given along with the dietary protein improve its utilisation by the tissues? In the case of fat, this has not been found to occur, but it has been demonstrated on both man and the lower animals that the presence of carbohydrate in the same meal as the dietary protein has a beneficial action on protein utilisation. The reason for this effect has not been fully investigated, but some clues have been provided by studying the action of carbohydrate, given alone, on the amino acids which continue to circulate in the blood of fasting animals. When a fasting subject takes a carbohydrate such as sugar, there is a period of a few hours during which the concentration of amino acids in his blood diminishes. By using amino acids labelled with radioactive atoms it is possible to trace where the amino acids go to. Radioactive amino acids have been injected into the bloodstream of rats just before administration of sugar, and in such animals it is found that a specially large amount of the labelled amino acid is deposited in the proteins of muscle. In other words, carbohydrate causes a reduction in circulating amino acids by diverting them into muscle tissue. It is not unreasonable to assume that, when protein is eaten along with the dietary carbohydrate, the process of deposition in muscle is even more pronounced. The nutritional importance of this interaction between dietary protein and carbohydrate is not easy to assess. Attempts have been made to show that the immature animal grows less efficiently when the protein and the carbohydrate of the diet are fed in separate meals, but we have been unable to confirm this. Further work will need to be done before we can say what the meaning of the phenomenon is.

In conclusion, it should be pointed out that these time factors in protein utilisation have only been disclosed as a result of rather unusual conditions provided by specially designed experiments. On ordinary mixed diets it is unlikely that effects due to the separation of nutrients will be encountered. These studies do, however, provide a means whereby the normal functioning of the body can be investigated and relationships between foodstuffs hitherto unsuspected can be revealed.

SOME ASPECTS OF AMERICAN INFLUENCE ON BRITISH EDUCATION[1]

by

PROFESSOR W. H. G. ARMYTAGE

ON October 10, 1877, John Ruskin wrote a letter to a Sheffield newspaper called the *Socialist* in which he said:

> Don't attempt to learn from America. An Englishman has brains enough to discover for himself what is good for England; and should learn, when he is to be taught anything, from his Fathers, not from his children (1).

This is an attitude of mind far more common in Victorian times than ours, and it betrays a growing awareness of the impact of American ideas on our national life. I do not want to prove that England is a cultural satellite of the United States of America, yet would like to point out that the matrix of our modern educational system is Atlantic rather than Continental. To do this involves a readjustment of our historical perspective of the last century or more.

I could perhaps begin two hundred years ago with the pervasive personality of the Philadelphia Prometheus, Benjamin Franklin, who had such an influence on the formation of the Royal Society of Arts or with Benjamin Thompson, Count Rumford, who founded the Royal Institution (2). But I prefer to start my story in October 1824, when thirty-four-year-old Francis Gilmer arrived in London as a talent scout for Jefferson's new university of Virginia. Gilmer distributed amongst his hosts, who included Lord Brougham, George Birkbeck, and Thomas Campbell, copies of the *Rockfish Gap Report*. This blue-print of a university free to students of all denominations was a stimulus to English educational reformers, most of whom had hitherto been content either to campaign, in a rather half-hearted way, against the religious tests which made Oxford and Cambridge preserves of the national church; or to compromise with injustice and send their sons to Scottish or European universities.

The Rockfish Gap Report aroused great interest amongst these English friends of Gilmer's. As I said, one of them was Thomas Campbell. Now Thomas Campbell's father was in the Virginia trade, his elder brother was living in Richmond and his younger brother had married the daughter of Patrick Henry. He saw that a non-sectarian university was being established at Charlottesville and was convinced another could be founded in London (3). And so it was, three years later, when Thomas Campbell took a leading part in forming a University of London on Jeffersonian lines. It stimulated others who wanted working universities to be established in other parts of England. Thus James Yates, who was later to be the first secretary to the Council of the British Association for the Advancement of Science, pleaded very powerfully for universities in the North and West of England, which should be untrammelled by sectarian tests. He was certainly under the Jeffersonian influence (4).

Yates was a Northcountryman—and to my mind represents the orientation towards America of the intellectual antennae of the great industrial north of England. America was to many of our northern ancestors, the utopia of the underprivileged. High society in the home counties might revel in the sneers of Mrs. Trollope or Basil Hall, but many northern merchants and artisans watched, with

[1] Address delivered to Section L (Education) on August 21, 1956, at the Sheffield Meeting of the British Association.

interest not unmixed with apprehension, the rising democracy on the other side of the Atlantic. Their feelings on this, as on many other subjects, were made articulate by Richard Cobden, perhaps the most effective political exponent of the American educational ideas in England during the period 1835–1865. Unjustly described by Carlyle as 'an inspired bagman with a calico millennium', Cobden early saw the threat which America presented to British industrial supremacy. In a pamphlet, published in 1835, he wrote:

> It is from the West rather than the East, that the danger to the supremacy of Great Britain is to be apprehended; that is, from the silent and peaceful rivalry of American commerce, the growth of its manufactures, its rapid progress in internal improvements, the superior education of its people and their economic and pacific governments—that is from these, and not from the barbarous policy and impoverishing armaments of Russia that the grandeur of our commercial and national prosperity is endangered. And the writer stakes his reputation on the prediction that, in less than twenty years, this will be the sentiment of the people of England generally: and that the same conviction will be forced upon the government of the country (5).

During his visit to America in that year he confided to his diary a resolution (unpublished until 1950) generated by the sight of an American school:

> Oh happy sight, pregnant with the hopes of the exaltation of the character of future generations. I hereby dedicate myself to the task of promoting the cause of the infant school in England where they may become an instrument for ameliorating the fate of children working in the factories whose case I fear is beyond the reach of all other remedies (6).

On his return to England, Cobden held, in 1836, a meeting in his counting-house at Manchester. To it came ministers of religion of every denomination. In an endeavour to initiate 'a system which it was proposed to try to agitate' Cobden used all his energies (7). But sectarian animosities proved too strong, and Cobden turned to the task which made his political name: the repeal of the Corn Laws.

When he returned to this educational crusade it was to encourage the Lancashire Public School Association (formed in 1847) to become the National Public School Association. He spoke powerfully and often on its behalf, both in the House of Commons and outside. On January 22, 1851, he said at Manchester:

> Where is our boasted superiority, when the American minister can come to the Town Hall here, and taunt us with the ignorance of our people and when nobody dares rise up and say, we have done as much for education as they have in America (8).

He followed this on May 22 by telling the House of Commons (W. J. Fox's Education Bill had just been rejected by 139 votes to 49):

> What I want is to have the same system of education in England that they have in Massachusetts, in the United States of America. I will not go to Louisiana or Georgia, but my system is that of Massachusetts and I challenge the Hon. Gentlemen to test that system by the experience of that State and the good it has effected there. . . .
>
> Where is the difficulty of our doing what has been done in Massachusetts. I will not be driven from that ground. Give me the Massachusetts plan. I declare my belief that the mass of the people in Massachusetts are as superior in intelligence to the population of Kent, as the latter are to the people of Naples. I say this advisedly. I ask, then, why we cannot have this system in England (8).

On December 1, 1851, he told the National Public School Association:

> We are the only people that have had voluntaryism and we are behind all the world. But in the United States they don't trust voluntaryism. They make use of their parochial and their municipal organisation to secure a system of schools free to all, paid for by all. . . . All classes are educated at the common public school (8).

Well might C. B. Adderley complain of this group, 'These gentlemen measured everything by the American model; if it fitted that model, any proposition was good ' (9).

Indeed, the N.P.S.A. as S. E. Maltby has shown (10), became one of the most powerful pressure groups for educational reform in England before 1870, putting forward three ideas which it took the House of Commons twenty years to digest: rate aid, compulsion, and control by locally elected representatives. These, argued the N.P.S.A., involved the establishment of school boards. School Boards existed in America long before they existed in England, and that they existed in England at all was due in great measure to the steady education of public opinion.

This education of British public opinion on the virtues of the American school board system was, of course, not solely the work of Cobden. Over three hundred British visitors published appraisements of the American scene during the period between Gilmer's visit and the establishment of the school boards in England in 1870. Though not predisposed to favour America, these travellers bore unanimous witness to its educational achievements. Wherever possible, the *Edinburgh Review* (which Sydney Smith, Lord Brougham and Leonard Horner had founded) bore their witness to a wider public. A characteristic remark was that of Sir Charles Lyell, the famous geologist, who after visiting a girls' school in Boston, confessed, after examining it, that he could not have expected more in an English public school (11).

The main feature of the American system as opposed to the English, was its public, non-sectarian character. New York was especially admired. James Silk Buckingham, the first Member of Parliament for Sheffield, wrote that American teachers were better than those employed by the voluntary societies in England (12). J. F. W. Johnstone, a lecturer in chemistry at the newly founded university of Durham, pointed out fourteen years later that the educational budget of New York State alone was larger than that of England, whilst that of Connecticut or of Rhode Island was even larger (13).

Philadelphia too, excited admiration. Alexander Mackay, a Scotsman employed by the *London Morning Chronicle*, described its 1,660 school districts and 80,000 pupils with approval in 1850 (14). The young Lord Acton, who held no high opinion of American institutions, kept his thoughts to himself, and did not publish his diary, but even he remarked that teaching positions in Philadelphia were paid so well that it was not uncommon for a minister to renounce his orders in order to teach (15).

On the attainments of American pupils there was astonishing congruity of opinion. Consider, for example, two English travellers of widely differing politics: Harriet Martineau, who stayed in the United States from 1836 to 1838, and J. R. Godley, who visited it in 1842. Miss Martineau was a Liberal and an admirer of America; Godley, as a Tory, not so. Miss Martineau said that the provision of schools was so adequate that the only children seen about were truants (16). Godley confessed himself 'astonished' in New York, at the literary proficiency of the negro pupils and their negro teachers, and remarked that their speaking and writing was far superior to that of the English working classes (17).

The way in which common schools served as avenues of social mobility excited admiration even from prejudiced observers of the general American scene. Mrs. Bishop in 1854 (18), H. A. Murray in 1855 (19) and T. C. Gratton in 1859 (20), one a young lady, the other a naval captain and the third a former British consul, all regarded it as one of the 'glories of America'.

Colleges and universities, however, provoked the same mixed feelings as they do today. Condemnations of their narrow vocationalism alternated with praise for their cheapness. Perhaps it is fitting to select the words of a hostile observer, Charles Dickens, whose novel, *Martin Chuzzlewit*, was certainly no advertisement for the Americans, to indicate the impression they made on one eminent Victorian:

They disseminate no prejudices; rear no bigots; dig up the buried ashes of no old superstitions; never interpose between people and their improvement; exclude no man because of his religious opinions: and, above all, in their whole course of study and instruction recognise a world . . . beyond the college walls (21).

One could go on to quote the contents of the numerous reports of British commissions which, in official language, said much the same thing. The remarks of George Wallis, Sir Joseph Whitworth (in 1854) and the Rev. James Frazer (ten years later) illustrate the growing awareness, by official observers, that American schools were, as James Frazer said, 'channels through which a desire for change and a desire to excel were inculcated' (22).

Reciprocal to this was the activity of Americans in England during the nineteenth century. Of the many who came in the steps of Franklin, Rumford and Gilmer, I will cite four for special mention. The first, Joseph Chessborough Dyer (23), was an agent for American inventions. He promoted Fulton's designs for a steam-engined boat and numerous improvements in cotton technology which made him a prominent figure in the public life in Manchester. There his work for the liberalisation of life has earned him a place in our own *Dictionary of National Biography*. The second was Moses Coit Tyler (24), who during the years 1863–6, contributed a great deal to the physical education of this country by his successful apostolate for eurhythmics. His ideas were enthusiastically endorsed by the Taunton Commission in 1867, who remarked that they provided the best solution to the problems of providing physical education in the large towns. A third was Elizabeth Blackwell (25), the first woman to graduate from a medical college (Geneva, New York, 1849). She came over to England and encouraged Elizabeth Garrett to try and do likewise. As you know, the University of London refused her permission to take the matriculation examination and as a result the movement for women's higher education was sparked off. Nor, in the story of women's education, should the part played by netball and lacrosse be forgotten. They were both American importations. A fourth was Thomas Davidson (26). Perhaps the briefest thing I can say about him was that he founded the Fabian Society. Indeed, were I permitted a little longer, I might give you an interesting talk on America and the British Left (27).

Indeed you can almost measure the strength of the American virus in English education by the activity of the anti-bodies. I quoted one of them, John Ruskin, at the beginning of this lecture. Perhaps more a representative and influential example, was Matthew Arnold who, as early as 1848, foresaw what he called 'a wave of more than ordinary American vulgarity, moral, intellectual and social, preparing to break over us'. Arnold particularly disliked the importance attached by Americans to utilitarian and technological knowledge, and in 1853 referred to 'the absence of any culture in America, where everybody knows that the earth is an oblate spheroid, and nobody knows anything worth knowing' (28). In this strain he piped for more than forty years, and in his Essay *Civilisation in the United States*, published in the year of his death, he lamented their mediocrity, vulgarity, and superficiality, all, in his opinion, faults arising in a country where, as he put it, social equality had been recognised before any high standard of social life and manners had been formed, and 'a considerable popular instruction [again I quote him] had been created without any serious higher instruction' (29). The Arnoldian stance was adopted uncritically and without his own reservations by many who should have known better. The Senate of Cambridge University, for instance, refused to accept an endowed lectureship in American history, literature and institutions, the holder to be chosen by the President and Fellows of Harvard, because of an unwillingness to feed what it called 'American conceit', and because it distrusted Harvard's 'unitarianism'.

Yet Americans knew what was worth knowing in the industrial world, and at the Paris Exhibition of 1867 the English came to realise this. Censured by *The Times*

(then being printed on presses made in Boston), the manufacturing class gave disturbing evidence to a committee appointed by Parliament to investigate technical education in England. Indeed, John Platt, the 'largest mechanical engineer in the world', who employed at his works in Birmingham 7,000 men, told the committee that it was 'the custom among machine-makers in England to purchase inventions from the Americans and adapt them for use in this country' (30).

This industrial paranoia, as we know, contributed in great measure to the establishment of School Boards in 1870 (31) and to the efflorescence (the image is justified by the architecture) of local colleges in the decade that followed.

American practice became increasingly a matter of governmental rather than private concern in the last three decades of the century, though the transition was rather prolonged. Sir William Mather, who was appointed to inspect American technical and vocational schools for the Samuelson Commission of 1882–4 and was, five years later, a keen promoter of the Act which endowed County Councils with the power to levy a rate for technical education, paid all his own expenses (32). American practice was also cited before the Cross Commission by E. F. M. McCarthy (33), whilst the Bryce Commission on Secondary Education (1894–5) utilised the services of J. J. Findlay, formerly headmaster of Wesley College, Sheffield, and later Professor of Education in the University of Manchester (34). American commercial rivalry as well as the excellence of their educational system was extensively cited in the debates on the 1902 Act. Findlay incidentally helped to make available in this country the educational writings of John Dewey by editing his *School and the Child* in 1906 and *Educational Essays* in 1910.

Acland, who set up the Bryce Commission, was also persuaded by his friend, Michael Sadler, to establish a Department of Special Inquiries and Reports on the model of the United States National Bureau of Education. This unique American intelligence service established under Henry Barnard in 1867 had, under him and his three successors, John Eaton (1870–86), Nathaniel Dawson (1886–9) and William T. Harris (1889–1906), built up a great tradition which excited Sadler's admiration. Acland agreed, and established a Department of Special Inquiries and Reports in 1895. The first volume of its reports contained an acknowledgement of its paternity. None can read volumes IX, X, or XI without realising how strong American influence had become by this time in English life (35).

For, at the twentieth century, American productivity was having decisive repercussions on industrial England. Between 1890 and 1900 American exports to England (excluding food, drink and tobacco) had doubled, and in that total, iron and steel exports had quadrupled. American locomotives were being used on underground railways in Glasgow and London, and were known as Yerkes Jerkers from the name of the builder, Charles Tyson Yerkes. (Incidentally an earlier American engineer, who laid the railway between Shepherd's Bush and Ealing, became the eponymous hero of our railway system—his name was G. F. Train.) The newspapers registered alarm, and the *Daily Mail* ran, in June 1901, a series of articles by F. A. McKenzie. These were subsequently republished as a book with the revealing title *American Invaders* (1902).

American penetration of the British Empire was even more startling. In New Zealand, for instance, their exports jumped from £200,000 in 1896 to £1,000,000 in 1901, and special commissions were sent to investigate conditions. Other commissions were sent to South Africa, and one of them reported in 1903, 'America is undoubtedly our most formidable rival, present and future' (36).

It was an Englishman in South Africa who set about trying to do what the newspapers, the Department of Special Inquiries and Reports, and the Liberal League were failing to do, and bring home to the English the seriousness of the lag between their educational system and the economic needs of the time. His name was Alfred Mosely. He had come to appreciate American technological skill whilst

mining in South Africa. His friendship with Gardner Williams (the famous California mining engineer who did so much for De Beers) and with Louis Seymour (who so successfully built bridges for the British Army during the Boer War) generated in him a desire to educate his countrymen on the virtues of American industrial training. So he returned to England where he gathered together two groups of experts. One was recruited from the English trade unions, the other from British universities and schools. Their departure to America was scheduled in 1901, but characteristically delayed until details of the 1902 Education Act were made known. Late in 1903 both groups left for America; the first consisting of twenty-three representatives of the Labour World and the second of twenty-five representatives of the Educational World. Each produced a report that had a considerable influence in the years before the first world war (37). The Board of Trade bought 3,000 copies of the Report and one M.P. wanted it issued as a parliamentary paper. The Labour Commission reported that:

> One of the principal reasons why the American workman is better than the Britisher is that he has received a senior and better education, whereby he has been more thoroughly fitted for the struggles of after life (38).

The Education Commission numbered amongst them the president of the N.U.T., the Professor of Engineering of this University, and Professor Henry E. Armstrong, one of the founders of this section of the British Association. Though, as might be expected, their individual reports varied, their joint opinion was:

> We are satisfied that, in the years to come, in competing with American commerce we shall be called upon to face trained men, gifted with both enterprise and knowledge. We desire to impress on the British public the absolute need of immediate preparation on our part to meet such competition (39).

It is interesting to notice that the most enthusiastic member of the Education Commission was Mr. Henry Coward, the President of the National Union of Teachers (40). W. P. Groser, another member, who represented the Parliamentary Industry Committee, was asked to write a book on *Education and Industrial Success* (1904) because he presented so strong a case for reform.

Perhaps the strangest detonation set off by the Mosely Commission was felt in the public schools. One of the members of the commission was H. B. Gray, the Warden of Bradfield, who is perhaps best known for his initiation of open-air Greek plays (in a disused quarry) near the school. Gray was invited to serve on the Mosely educational commission in 1903 and it proved a Damascus road for him. He put on record that the teaching of English in America was 'remarkably good, and far outstrips anything of which we can boast', whilst the 'teaching of science in all its branches appeared admirable'. So impressed was he by American schools and curricula that he devoted the rest of his active and energetic life (after his retirement from Bradfield in 1910) to a spirited campaign against the caste nature and didactic system of English public schools. His was the bitterest and most thorough criticism which English public schools had yet received from one who knew them as a responsible person (41). It was a plea for a flexible and original curriculum based on observation of men and nature. Public Schools, in his view, should not aim at producing prancing pro-consuls and rulers of inferior peoples, but participants for a co-operating commonwealth.

Mosely was responsible too for initiating in 1906–7 the visit of several hundred school children to the United States and Canada, a project first mooted by Choate, the U.S. Ambassador in 1901. In 1909 the then Vice-Chancellor of Sheffield conceived the notion that a twentieth-century 'grand tour' should embrace the New World and a movement was set on foot to promote it. In 1910 the Central Bureau for the International Exchange Students opened to increase our 'efficiency as

citizens'. In 1912 the first congress of the Universities of the British Empire proposed that British universities should establish the Ph.D. degree to attract research students who were flocking to America or Germany. The Foreign Office supported this in 1916, and in 1917 the five universities who comprise the joint Board led the way in doing so. After the war the great academic hegira swelled to formidable proportions and foundations endowed by Rockefeller, Harkness, Brooks Bryce, and Walter Hines Page sent to America the cream of English Universities, some of whom were so attracted by what they saw that they remained (42). In 1924 the British Joint Committee for the Interchange of Teachers was established within the framework of the English Speaking Union and continues to work with unabated energy to this day.

It is ironical and paradoxical that the wealth being rolled up in the United States by Carnegie and Rockefeller did far more for English education than that accumulated by Englishmen. 'Who dies rich, dies disgraced', said Carnegie and he and Rockefeller did much to cushion the English against having to pay for their university buildings until the close of the second world war. Carnegie gave handsomely to Birmingham University and to individual town libraries in this country, while the United Kingdom Trust which he founded in 1913 was responsible for inaugurating the county library service. Indeed, until Parliament passed the necessary legislation in 1919 enabling local authorities to spend more than 1*d.* rate on library services, the Carnegie Trust sustained it. It housed the National Central Library and encouraged the construction of playing fields, the Cambridge village colleges, and museums (43). The Rockefeller Trust was even more generous. They made it possible, by a gift of five million dollars in 1920, for University College Hospital to become a model for the British Commonwealth. Similar large capital sums enabled the Universities of London, Cambridge and Oxford to build libraries (44).

Nor should two American efforts like those of Carl Vrooman and the Elmhirsts be forgotten. Carl Vrooman established Ruskin College with Charles Beard in 1899 and when he appealed to that eminent English educationalist, Herbert Spencer, for books, Spencer haughtily replied that he had 'a profound aversion to the teachings of Mr. Ruskin, to Socialism and Free Libraries'. Shaw, at the same time refused to lecture there on the grounds that the 'real business of Oxford was to make a few scholars and a great many gentlemen' (45). The second American effort was the establishment by Mr. and Mrs. Elmhirst, in the dark days of 1925, of Dartington Hall as a vehicle of rural reconstruction and education. The story of this venture would repay a lecture in itself, but it must be said that it has provided a stimulant (and irritant) to all those who care deeply about enabling everybody to enjoy their full range of human achievements and experience.

That to my mind is what has made America one of the decisive determinants in English educational development, for it was the first nation to face the problem of educating everybody. No American school, whatever its material drawbacks, could afford to confess itself a third-class waiting-room for adult life. To cope with the thousands that funnelled out into the west, new types of schools had to be built and new techniques of teaching in them improvised. It is no coincidence that many of the techniques that, with modifications, have been found so stimulating in our own new secondary schools are The Gary Plan and The Winnetka Technique (both worked out in districts near Chicago), the Project Method, and the Dalton Plan (46). Of these, the Dalton Plan made by far the greatest impact upon English classrooms, especially between the first and second world wars. Among its great English protagonists were Dr. C. W. Kimmins, a stalwart of this section (he was president in 1929) and for many years chief inspector of the London County Council (47), Aldous Huxley, who gave great publicity to the most distinguished English exponent of the plan (48), A. J. Lynch of West Green School, London, and Sir John

Adams, whose book *Developments in Modern Educational Practice* was widely read in the nineteen-twenties and thirties.

Because Americans accepted the challenge to educate everybody and study all the activities of human life, their universities scoured Europe for ideas and techniques with which to undertake the task. They regarded education itself as a process which could be studied and applied. Their travelling enthusiasts were the first to adopt and put into practice the ideas originally generated in Europe by Pestalozzi and Froebel. Indeed, much of the German literature on Education was first Englished by Henry Bernard, the thirty-two volume of whose *Journal of Education* were for a long time, if not still, regarded as an indispensable quarry. When Wundt opened the first psychological laboratory in Europe, Americans were amongst his keenest students. Two of them on their return made possible the establishment of educational psychology: J. McKeen Cattell, and G. Stanley Hall. And one of Cattell's associates, E. L. Thorndike, nourished in our defeatist twentieth-century atmosphere a warm belief in the improvability of man and the belief that by education it could be effected. Europe might regard Paradise as lost, but for Americans it could be perpetually regained. The first journal devoted to child psychology—Stanley Hull's *Pedagogical Seminary*—was founded there in 1891 and the first psychological clinic for children—Witmer's at Philadelphia in 1896. In that same year, 1896, J. McKeen Cattell pioneered in mental testing by publishing a study of physical and mental tests of Columbia students. It was in the *American Journal of Psychology* that Spearman published the great article adumbrating his concept of 'g' and 's', and it was to America he went in 1931 just as Tichener and McDougall had done before him. These tests, one must insist, first originated in England with Galton but their application on a wide scale was to two million recruits of the American Army in 1917. Only America would have dared use them, at that time, and the enormous data obtained thereby has proved of incalculable value in applying tests to wider problems. Thus 'tests' have been applied to imigrants to the United States and the results have enabled the government to fix a 'quota' for various countries. America has helped the English to adjust their many-tiered, deeply embedded, educational system to the conditions of modern life. The American frontier, moving westwards, pulled at the class layers of English Society. And as the frontier moved westwards, prairie corn destroyed the amateur English farmer and American inventions rapidly supplanted the expensive English handicraft worker. The very pace of American technological change precipitated the solution of social problems long shelved (or at best tentatively handled) in our own industrial areas.

American had no competitive institutions, like churches, to challenge the mystique of the school and the college, nor did America have a tangible, visible, potent past to enfold and conservatise them. Thus their schools and colleges could plan for an indefinitely expanding future, fostered and nourished by endowments that have had no parallel in the history of the civilised world. It was this stupendous munificence to universities which led observers like Sara Burstall (49) and Sir Michael Sadler to comment that 'education was one of the religions that Americans believed in'. As Sadler remarked in 1921 'It has its orthodoxy, its pontiffs, its noble buildings. Education is the Established Church of the United States' (50).

The peculiar strength of our island civilisation has been its power to apprehend and absorb the best of continental and transatlantic practice, and apply it empirically. Being empiric, we have not had such a formidable stock of exegesis and commentary upon our system as the Americans and Germans have had upon theirs. Perhaps this is due to the fact that we are aware of what we owe to them and do not like acknowledging it. Even today, one hears the argument advanced that social conditions in America and England are so different that American experience is valueless in England. But those who advance it forget that technological and

cultural change are great standardisers: they forget that the complex interweaving of the civilisation of one country by another is effected, not only in the schools, but in the laboratories, the factories, the shops, the cinemas, the boardroom, the learned societies, the banks, the churches. Yes, and even on the tennis courts, racecourses and boxing rings. Ruskin told readers of Fors Clavigera in 1871, 'every line when in this letter I have used an American expression, or ought like one, there came upon you a sense of sudden wrong—the darting through you of acute cold. I meant you to feel like that: for it is the essential function of America to make us feel like that'. And America has been making us feel like that for the past century and a quarter.

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Larsen, Egon: *An American in Europe* (1953).
(3) Bellot, Hale: *University College*, London (London 1929), 16.
(4) Yates, James: *Thoughts on the Advancement of Academical Education in England* (London 1827), 44–5, 145. B. A. Hinsdale, *op. cit.*, 598–9, is concerned with Jefferson as 'a propagandist of French science, arts and educational ideals.'
(5) *England, Ireland and America* (London 1935): By a Manchester Manufacturer.
(6) Armytage, W. H. G.: 'Richard Cobden in Illinois', *Journal of the Illinois State Historical Society* (Springfield 1950), **xliii**, 187–203.
(7) Cobden's interest in education was so well-known and regarded that we find Matthew Arnold enlisting his support, W. H. G. Armytage, 'Matthew Arnold and Richard Cobden in 1864: Some New Letters', *Review of English Studies* (Oxford 1949), **xxv**, 249–54.
(8) Bright, John & Thorold Rogers, J. E. (ed.): *Speeches on Questions of Public Policy* (London 1903), 596, 600, 609.
(9) *Hansard*, **cxxx**, 1049–50.
(10) Maltby, S. E.: *Manchester and the Movement for National Elementary Education 1800–1870* (Manchester 1918), 48.
(11) Lyell, Sir Charles, *Second Visit to the United States* (London 1849), **1**, 189.
(12) Buckingham, James Silk: *America* (London 1841), **1**, 203–4. Buckingham was not only a pioneer town planner in England (Lewis Mumford, *The Culture of Cities* (London 1940), 394) and the first M.P. for Sheffield, but a pioneer of self-government for the colonies (*Cambridge History of the British Empire* (Cambridge 1940), ii, 405). He was also a notable publicist and founded *The Athenaeum*, *The Sphynx* and *The Oriental Herald and Colonial Review*.
(13) Johnstone, J. F. W.: *Notes on North America* (Boston 1851), **ii**, 491. Johnstone was an early teacher of science at the new (founded 1832) University of Durham.
(14) Mackay, A.: *The Western World* (London 1850), **iii**, 234–5.
(15) Acton, J. E. E. D.: 'Lord Acton's American Diaries', *Fortnightly Review*, **cx**, 727, 917–34; **cxi**, 63–83. See **cxi**, 80.
(16) Martineau, Harriet: *Society in America* (New York 1837), **ii**, 269.
(17) Godley, J. R.: *Letters from America* (London 1844), **ii**, 33–4. He was not so impressed, however, by the conditions in the South.
(18) Bishop, I. L.: *An Englishwoman in America* (London 1856), 436.
(19) Murray, H. A.: *Lands of the Slave and the Free* (London 1855), 377.
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(21) Dickens, Charles: *American Notes* (Boston 1867), 10, written from his experiences in 1842.
(22) Burn, D. L.: 'The Genesis of American Engineering Competition 1851–67', *Economic History* (London 1930), 309. James Frazer was serving as a commissioner for the Schools Inquiry Commission, appointed in 1864, to examine the endowed schools in England. For his report, see *Report of the Schools Inquiry Commission*, 1867, **xxvi**, 496.
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(24) Jones, H. M.: *The Life of Moses Coit Tyler* (1933) and *Report of the Schools Inquiry Commission* (H.M.S.O. London 1867), **iii**, Appendix XII, pp. 587 ff.
(25) Blackwell, Elizabeth: *Pioneer Work in Opening the Medical Profession to Women* (London 1895).
(26) Armytage, W. H. G.: 'Thomas Davidson: The Wandering Scholar', *Aberdeen University Review*, **xxxiii** (1950), pp. 430–4.
(27) See Pelling, H. M.: 'The American Economy and the foundation of the British Labour Party', *Economic History Review*, **iii** (1955), pp. 1–17.
(28) Russell, G. W. E.: *The Letters of Matthew Arnold* (London 1895), 4.
Lowry, H. F. (ed.): *The Letters of Matthew Arnold to Arthur Hugh Clough* (1932), 132.
(29) See, for example, Connell, W. F.: *The Educational Thought and Influence of Matthew Arnold* (1950), 70; *Culture and Anarchy* (1869), 17 ff; *Mixed Essays*, 'Equality'.
(30) *Select Committee on Scientific Instruction*, pp. 1867–8, Q 5671.
(31) See, for example, speech of the Duke of Marlborough on the Second Reading in the Lords in *Verbatim Report of the Debate in Parliament during the Progress of the Elementary Education*

Bill, 1870 (published by the National Education Union, Manchester 1870), 524–5. The National Education League, after securing the passage of the 1870 Act, continued to press for the adoption of American ideas. Its secretary, Francis Adams, as part of the campaign to abolish fees in the newly established Board Schools, published a report on the *Free School System in the United States* (1875) to supply as he said 'English reformers with the means of insight into the operation of the American system of Elementary Education'. In the same year Jesse Collings, Joseph Chamberlain's friend, published *An Outline of the American School System: with remarks on the establishment of common schools in England*, which the friends of the comprehensive system have no doubt considered. A leading member of the League, Sir Charles Dilke, had already called attention in his *Greater Britain* (1866) to the accessibility of American state universities to everyone, and posed the question as to whether such accessibility might not be developed in England.

(32) MATHER, L. E., SIR WILLIAM MATHER (ed.): (London 1926). Sir William Mather was a disciple of Emerson who obtained the rights for manufacturing an American dynamo. He pioneered the first tube railway in London and was one of the promoters of the Technical Instruction Act of 1889.

(33) *Royal Commission on Elementary Education 1886*, Reports P.P. 1888, ed. 5845, ii–iv.

(34) *Royal Commission on Secondary Education*, **vi–vii**, pp. 339–407.

(35) See, for instance, HIGGINSON, J. H.: *Sadler's Studies of American Education* (Leeds 1955).

(36) HEINDEL, R. H.: *The American Impact on Great Britain* (Philadelphia 1940).

(37) See, for instance, the collateral agitation of Sir Norman Lockyer, which results in the formation of the British Science Guild in 1905.

(38) *Mosely Industrial Commission to the U.S., Report of the Delegates* (Manchester 1903).

(39) *Report of the Mosely Educational Commission to the U.S. of A., Oct.–Dec. 1903* (London 1904), and A. Edmund Spencer, *Random Notes on the Mosely Education Commission* (reprinted from *Western Morning News*, 1903). It was also published in the *Annual Reports of the Department of the Interior (Commissioner for Education)* for 1905 (Washington 1907), edited by W. T. Harris, pp. 1–37.

(40) The personnel of the Mosely Education Commission contained eleven representatives of the new local education authorities created in 1902. The districts they represented were important ones: London, the West Riding, Newcastle, Sheffield, Liverpool, Manchester and Rochdale. Other authorities, which had not been represented on it, soon took steps to remedy their deficiencies in this respect. Leicester sent a deputation which reported in 1907. Reading (backed by L. Sutton, the seed merchant, and Alfred Palmer, the biscuit manufacturer) sent a fact-finding group to examine American agricultural colleges which reported in 1910. The permanent officials of the authorities, whom we would now refer to as their directors of education, sent a deputation on their own in 1911 to examine technical schools, and this report, compiled by the secretaries of the Barnsley, Ealing, West Bromwich and St. Helens authorities, were warm in their praise of American vocational schools as compared to English ones. National Association of Education Officers, *Education in Relation to Industry: A Report on Technical Schools in Canada and the U.S.A.* (Leeds 1912). In short, the local authorities so primed themselves with information about technical schools and colleges in America that when, in 1918, they were empowered to levy more than a twopenny rate to finance such colleges, they went ahead, prodded by the various professional associations, to emulate what they had seen.

(41) *Public Schools and the Empire* (London 1916). See also his *Eclipse or Empire* (London 1916) and *Industrial Education in America* (London 1917). He was president of Section L at Winnipeg in 1909.

(42) For example, BARNARD, C. I.: *Rockefeller Foundation Directory 1917–1950*, shows that this foundation sent to America the following post graduate research students: 136 medical sciences, 114 natural sciences, 108 social sciences, 16 nursing, 13 humanities, 4 public health.

(43) See *Centenary of the Birth of Andrew Carnegie* (1935). The real credit for the proposal goes to W. G. S. Adams, who wrote the report for the Carnegie Trustees. Nineteen authorities were so helped before 1919.

(44) FOSDICK, R. B.: *The Story of the Rockefeller Foundation* (London) 1953. The trusts were consolidated after 1928. Amongst other sustentions must be mentioned two million dollars for the London School of Hygiene and Tropical Medicine in 1922; the placing of a carefully selected group of medical students in 1941–2; The Royal Institute of International Affairs; Rothamsted Experimental Station and *The Encyclopaedia of the Social Sciences*.

(45) *The Story of Ruskin College* (Oxford 1952).

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POPULATION AND THE SOCIAL SCIENCES [1]

by

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WHEN, in past years, we have listened to, or read, the presidential speeches delivered by our distinguished scientific colleagues to this Association, we *may* have had, as economists, twinges of conscience on recognising echoes of population theories long discarded from our own thinking; or, then again, we may not. Economists are, after all, themselves divided on *policy*. But nearly all of us would agree with the proposition before us now, that the theory of population has occupied a much less central place in economic theory in the twentieth century than in the early nineteenth. If we happen to agree with the prophesiers of woe, we do so less in our capacity as economists than as citizens.

The proposition that population theory has lost its central position in economics can be readily proved by quotation, so it would be otiose to attempt such proof now; instead, it may be useful to examine our own minds on the place that subject should occupy. I shall try, then, to use my space not to give *chapter and verse* for this historical sketch and review of current ideas that I shall attempt. Instead of bandying names and dates about, I shall try to examine the background, and present status, of population theory as part of economic thought.

What I am discussing is not whether the status of population theory has changed, but *how* it has changed, and what the position is today.

An early economist, justly renowned, made the principle of population, which he did not invent, the centre of his theoretical system. The natural price of labour, he thought—by which he meant the long-run price to which the market price would tend to adjust itself—is the price which is necessary to enable the labourers to subsist and to perpetuate their race, without increase or diminution. He conceded that custom played its part, and that, after a period when the market price exceeded the natural price, or subsistence level, the acceptable standard of living might go up. But he removed the force of this concession later when he added that the delights of domestic society were so great that in practice it is *invariably* found that an increase of population follows a temporarily amended condition of labourers' lives. With this empirical observation, which can be treated as an essential hypothesis, a whole system of economics was worked out. Combined with the law of diminishing returns, and with an assumption about the supply of land, rents, profits and wages were determined.

The earlier economists were advocates of policy. They claimed that their scientific analyses led to precise conclusions. Applying their principle of population to the question of the poor laws some of them argued that they had proved, beyond all question, that these laws, if not repealed, would lead to the nation being infected with universal poverty.

The principle of population played its part, thirdly, in their dynamic view of the long-run tendencies of profits and rents. Of course, there was not just one classical view but several. According to one view, profits were the stimulus of capital; hence they increased the power in society to employ more labour, and hence led to an increase in the total income of society. On this view, the only bottleneck that could arise would be an inelastic supply of food to maintain the increased supply of labour.

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There is no need to elaborate these familiar arguments. But it may be worth noting that there were three aspects to them: the formal static theory, the applications of theory to the actual current situation, and the development of a dynamic view. The last is inadequately described as a dynamic theory; it was not just a hypothetical model, but a working model, as close an approximation to reality as the author could make it, and one through which a gifted man expressed his vision of society as pungently and persuasively as possible.

The same features may be discerned in later economists, down to the neo-classical school. Some were pessimistic and others optimistic; all tried to be politically relevant.

Let us look briefly at the views of the successors to the early classical school. They were almost bound to take the point on policy, and on the long-term dynamic outlook, that things were not necessarily so gloomy as the leading writers of 1815 had made out. For while agriculture was still according to them likely to be subject to diminishing returns, manufacturing was quite possibly, over a very wide range, subject to increasing returns. 'Every increase in the number of manufacturing labourers is accompanied by an increased productive power', was the doctrine, and it followed that 'the only check by which we can predict that the progress of our manufactures will in time be retarded, is the increasing difficulty of importing materials and food. If the importation of raw produce could keep pace with the power of working it up, there would be no limit to the increase of wealth and population'. These words, published in 1836, provide just about the same analysis of Britain's position as that offered a hundred years later by leading applied economists, with the difference that the earlier writer was optimistic while the later ones were pessimistic. They, too, thought that the main bottleneck to our increasing wealth lay in diminishing returns to the procurement of food and raw materials from overseas.

There were, of course, pessimists in the nineteenth century as well as today. Some already pointed out that population growth in the wheat-exporting countries might (or, as some of them thought, would) prevent their maintaining an export surplus. Some even foresaw the alarming prospect in the near future of progressively worsening terms of trade. So far as systematic thinking was concerned, one of the most interesting developments was the invention of the theory of the stationary state. 'It must always have been seen, more or less distinctly', wrote one systematiser, 'that at the end of what they term the progressive state lies the stationary state; that all progress of wealth is but a postponement of this . . .' This was seen not as a theoretical possibility, but was predicted as an unavoidable ultimate historical necessity. 'The doctrine that, to however distant a time incessant struggling may put off our doom, the progress of society must end in shallows and in miseries, far from being, as many people believe, a wicked invention' was perfectly sound, and a doctrine of long antiquity. To postpone the evil day as long as possible some form of conscientious or prudential restraint on population increase was indispensable. The same writer, rather surprisingly in view of his earlier characterisation of the stationary state as a shallow of miseries, also wrote that he preferred stationariness to progress, and opted for that state itself. 'I am inclined to believe that it would be, on the whole, a very considerable improvement on our present condition. I confess I am not charmed by the ideal of life held out by those who think that the normal state of human beings is that of struggling to get; that the trampling, crushing, elbowing, and treading on each other's heels, which form the existing type of social life, are the most desirable lot of human kind . . .' In the United States, he observed, where 'they have the six points of Chartism and they have no poverty . . .' nearly 'all that these advantages seem to have for them . . . is that the life of the whole of one sex is devoted to dollar-hunting and of the other to breeding dollar-hunters.'

We may smile at these value judgments; or we may repeat them in our own peculiar twentieth-century English. Which we *should* do, I do not at this moment, intend to discuss. The point is, however, that in the age when population theory was central to economics, judgments of value were also regarded as part of political economy, and quite unaffectedly linked with *obiter dicta* on the then current population question. For example: 'The density of population necessary to enable mankind to obtain, in the greatest degree, all the advantages of co-operation and of social intercourse, has, in all the more populous countries, been attained.'

Towards the end of the century, British economists began to evolve a more neutral 'optimum' theory of population. The dangers of under-population as well as over-population were noted, and the obvious point arose that there must be some critical size which, in any given set of conditions, and granted also an assumption on the ends of economic activities, could be described as optimum. A thinly peopled country might experience increasing returns in all branches of industry, except agriculture and mining, it was thought, for a considerable period of growth. During that period, the greater the increase the greater the utility per head available, owing to the advantages in communication and transport due to human proximity. As for the differing ends of the state, it was recognised that the optimum might vary if, for example, considerations of military or commercial rivalry, and not mere material output per head, entered into the ends served by the society.

The neo-classical school avoided the trap of taking up and developing the concept of an optimum population, although they continued to recognise that a country's population might be too large or too small. Presumably they thought that the optimum was too difficult to determine to be useful as a tool of analysis; it was a concept that would have to be hedged around with too many qualifications to fit into a realistic theory.

As for the danger of over-population, they thought that the indefinitely rapid increase in population characteristic of Western Europe in 1900 could not continue 'for many hundreds of years' simultaneously with any wide spread in the habits of comfort then prevailing in Europe. Like earlier writers, the ultimate danger of adverse terms of trade to Great Britain, was regarded as liable to be brought closer by increases of population in the countries supplying raw materials, especially if the number of producers of these raw materials were so reduced as to put them in a position of unassailable monopoly.

But the great contribution of the neo-classical school lay not in its observations on the current situation, but in its frank recognition that population growth, in one way or another, might stimulate or make possible the general development of industry, and that this in turn might result in increased economies and in increases in output per head. This was not a new point, but it had not earlier been discussed with the thoroughness of the neo-classical treatment. General development of industry led to both (*a*) inventions, and changes in the state of the arts and to (*b*) improved organisation, and both (*a*) and (*b*) promoted increased returns to scale over time. Exactly what changes were to be included under the two headings was never definitively laid down, but has been discussed at length since. Increasing returns might include both external economies and internal economies as production increased.

This was by no means an exclusive part of the analysis; population growth was only one force at work, and not necessarily the most important, but the recognition that it could be important was a striking development.

The world view was this: increased production will increase the size, and therefore up to some point the internal economies available to the representative firm in any industry. It will also increase the external economies available to that firm. So there will be an increased quantity of product available for any given unit expenditure in terms of effort and sacrifice. This will lead to another stage of industrial

expansion, and the final result *may* be some increase in welfare. But the neo-classics pointed out that such a connection was not a necessary one, because industrial expansion may be accompanied by the too rapid growth of unhealthy and overcrowded towns, or it may be ill-balanced, or it may outrun the raw materials available at reasonable cost, so bringing the 'diminishing returns' restriction into operation at one point or another.

Despite all these qualifications, the doctrine was clear; that the collective industrial efficiency of a people might well increase in some periods out of proportion to any increase in their numbers; and that this kind of increasing returns could even occur without the aid of new techniques. This closed the door on some versions of pessimistic economics.

Population theorising still played some part in neo-classical equilibrium theory, as well as in their world view. Short-period wages theory could be accounted for without recourse to population theory, since 'in fact there is no such thing in modern civilisation as a general rate of wages'. Each group of workers has its own wages problem, and the supply of labour to each of these different specific markets can be treated in terms of the special conditions of entry, the available types of education and upbringing and so forth. For the longer period, some relics of the old classical reasoning would be salvaged. Wages could be regarded as tending, in some way, to retain 'a close though indirect and intricate relation with the cost of rearing, training and sustaining the energy of efficient labour'. But this would only really be important if the economic conditions of the country remained stationary for a sufficiently long time. Wages, in the long-period, we are also reminded, are not governed by demand-price nor by supply-price, but by the whole set of causes which govern demand and supply. So while the full doctrine of the classical argument is discarded, that *part* of it is left which relates *part* of the causes of labour supply to the cost of production of labour.

The 1920's saw a notable revival of the pessimistic views of the early nineteenth century. The law of diminishing returns was restored to a central place, as a predictive historical generalisation. Even the less orthodox brilliant economists of the day began to wonder whether or not 'the magnificent episode of the nineteenth century' was over, because of renewed population pressure. This 'magnificent episode' idea continued to be a hall-mark of economists' speculation for some time; but their world view instead of being the meat of their work very often was relegated to footnotes.

However, towards the end of the 1920's there was a counter-attack on pessimism, and revived discussion of the optimum size of population. But suddenly and abruptly, round about 1930, population theory was dismissed from economics as such. It had always been recognised, of course, that the determinants of births and deaths included other than economic factors. Just about the time that discussions of overpopulation were wound up and discussions of underpopulation began, a tacit decision to leave prediction of population to demographers and statisticians seems to have been reached. Orthodox economics for the next two decades treated, by and large, population changes as exogenously determined. The old hypothesis that a rise in standards of living to a certain level would cause certain changes in population was not replaced, but abandoned. So, in accepted works on wages theory the population available for work was treated as a datum on which topic the economist neither could, nor should, say anything whatsoever. The subject was henceforth relegated in universities to sociologists or to demographers.

So, in the 1930's, there began to appear studies of the economies of a declining population, which treated the fact of that decline as a datum, and speculation on the secular stagnation from which the British and American economies would shortly suffer in consequence of the predicted slowing rate of increase, and ultimate decline, of its population. It was a period in which economists, in a way, lost their nerve,

and, arch-inventors of bogies themselves, called in a new discipline to invent bogies for them to be scared of.

This episode is now over. We are not concerned *why* it happened—that would be an interesting question but there is no time to pursue it here—but with *how* it happened, and in what shape the science of economics has been left having cast aside, only temporarily I believe, a central concern with the relationship between population and economics. For there can be little doubt that with our revived interest in economic growth, population theory cannot be left wholly to other disciplines.

The date at which population theory came to be dropped was that when the economic historian's plea to know which industries showed increasing returns and which did not had just fallen not on deaf, but on perverse ears; for instead of inaugurating a decade or two of applied economics designed to answer the question, the discussion proceeded rapidly on to a theoretical plane somewhat tenuously connected with the originating problem. The definition of terms like 'firm' and 'industry' were re-examined, and 'imperfect competition' theory developed. The simple-minded idea that it might be useful to be able to identify increasing returns when they occurred, and to measure their extent, tended to be rejected as naïve.

Secondly, another shift in emphasis was away from theories of particular equilibrium towards theories of general equilibrium.

Thirdly, a sharper distinction was made between positive and normative economics, and much of the classical and neo-classical speculation on the world's future was ruled out of order, by those who took it upon themselves to define the field of economic teaching.

I do not wish to suggest, by these cursory references, that these developments in economics were in themselves undesirable or uncalled for. On the contrary, with other students of economic thought, I find that 'our science' has progressed by way of controversies, some of which no longer seem wholly relevant, but out of them may have come some new power of analysis.

The consequence of the discussions on the nature of economics that took place in the 1930's is that all economists nowadays tend to be more conscious of the distinction between analysis and pronouncements on policy than they once were. At one time, a professor of economics could take part in a campaign to publicise the dangers of the abuse of alcohol without apparently being aware that this activity was not part and parcel of his duty to society as an economist.

But while we distinguish between analysis and policy recommendations, we are—or some of us are—happier than we once were about our rights as economists to give expert advice on matters of economic policy. However, I do not intend to discuss policy directly today.

If analysis is neutral, it can handle theories of increasing returns, for example, as easily as of diminishing returns. The classification of external economies can proceed much further than the neo-classical writers had gone, and the empirical study of external economies can also be developed.

Theories of growth are also ostensibly neutral. On one set of hypotheses, growth rates will show unstable equilibrium or progressive stagnation; on another, they may show increasing production and increasing population over ranges of growth even without increasing returns.

Finally, in the field of applied economics, without attempting to outline any world view, we may still attempt to discover what are the relevant ranges of application of our hypotheses, and of course, which hypotheses to apply.

Nor do I wish to suggest that the relegation of population to sociology and demography was a wholly retrogressive development in the history of the social sciences. From the moment that population changes began to be examined in their historical setting systematically, and from the moment that inductive, instead of deductive, laws of population change were sought, it became necessary for social

scientists to use techniques of sociology rather than of economics alone. The structure of the family, marital laws and customs, and the values fostered in different societies come within the field of discussion. Similarly, the advance of statistical analysis of population soon led to the necessary development of demography as a specialised discipline for handling vital statistics and analysing trends, and has become one of the most interesting and fruitful fields of mathematics applied to human affairs. Economists do not in the least decry the specially notable advances in demographic techniques which have occurred in recent years, nor those developments of sociology which attempt to study many more implications of our social relationships than those that are, by any generally acceptable definition, to be treated as economic.

What is open then to criticism? The tendency among economists to wash their hands of a problem? It is arguable that this process has gone very much too far.

Several examples of the unfortunate consequences of economists excusing themselves from having a population theory at all could be constructed without much difficulty.

First, there was the abandonment of any serious economic thinking on the basis of prediction of the future growth of population in the advanced industrial countries of the world. The predictions made for the United States were particularly wide of the mark. There was an extraordinary neglect of systematic study of the growth of cities and metropolitan areas—even today the basic statistics are not easy to assemble—and also of, until recent years, study of the economic forces determining internal and overseas migration. No doubt many of the huge migratory movements of the twentieth century have been politically rather than economically determined. Even so, the economic importance of migration has not been negligible. Further large migratory movements are possible, and to say the least we ought to have some opinion on their possible economic consequences. Secondly, in the study of underdeveloped countries, and in the drawing up of their plans for future development, it soon became apparent that economists had uncertain views as to the order of priorities to adopt; in the Western economies they were more preoccupied with problems of cyclical unemployment and with the relevant theories than with the kind of problems that arose in countries with large supplies of labour, or the economic problems of a social system that still encouraged something like the maximum possible pregnancies among its married female populations of child-bearing age. It is not likely that these, or other problems, could be understood without sociological theories as well as economic; the point is that economic theory and knowledge were not well equipped in, say, 1945 to tackle their share of the explanation of the forces at work. Some of these could, in a sense, be better understood by use of the classical model, than of some Keynesian model, since labour seeking work in the modernised or industrialised part of the economy was practically unlimited, but this did not imply a simple return to the classical view of the inevitable long-run dependence of population upon subsistence.

Moreover, the interesting point was how the economy could break through from its existing vicious circle of poverty, and the only way even to imagine such a change was in terms of how the economy would work when some big change in its assets and in industrial structure had taken place. This involves, one way or another—with detailed refinement or in terms of rough-and-ready speculation—some model building. While sociologists could make useful contributions to speculation on the break-through from poverty—for example, in deciding which were the institutions most likely to be modified so as to make the society capable of adopting some modern production techniques—they alone were not capable of expert theorising on the economic development required. Economists had to learn again to think of the consequences for an economy of population changes of serious magnitude. Or, to take a third example: the study of town planning applied to a

large conurbation. The statisticians are able to tell us how many people commute daily (to use a useful Americanism) to and from their place of work. The sociologist announces that this is muddled, unhealthy, and uneconomic because of the cost and wear and tear of travel, and undesirable. The policy recommendation is, then, to build factories and places of work near where the people seem to want to live. However, new people from other areas move in to these new towns. Even more people, the statisticians tell us, are commuting to and across the centre. The sociologist then recommends that dwellings should now be built in the centre nearer to the central places of work. *But* there is not the slightest guarantee that this will not exacerbate instead of diminishing the problems of overcrowding and daily transport.

The variables which the economist would, or should, have been anxious to study seem to have been badly left out of some current discussions of these problems.

Of course, one reason that the economist is quite ready to leave such questions to others, is that, in the present state of the art of applied economics, he would have very little to contribute in exact quantitative terms. But I especially mention underdeveloped areas and town planning because it seems that any serious new economic contribution to the understanding of the factors affecting population growth will have to include an understanding of the economics of those areas and of urban growth, using the last term in a very wide sense to include the growth of conglomerations of persons living within organised interconnected metropolitan areas.

Because, perhaps, of the very great variety in the patterns of growth of these areas, and because of the difficulty of analysing all the main economic factors at work—complicated as these are by non-economic factors—the subject has been somewhat neglected both theoretically and in applied studies, except from the very special points of view of unemployment and social costs. But a revived interest in building models of growing economies may, from a different starting point, provide analytical tools suitable for a better understanding of metropolitan growth, and hence of some of the main reasons for modern population increase.

If we can imagine two Scotsmen in say, 1880, discussing the future population of their country, and estimating what it might be in 1910 or 1950, who would have made the best guess, if one knew by heart all the birth and death rates of every parish in Scotland, and the other knew the input-output relationship for industry and could estimate fairly well the world demand for the products of Scottish industry? Birth and death rates alone would have indicated large increases in population in the Highlands and Islands.

Economists quite rightly do not, however, make very bold claims for their own powers of prediction, of population movements or of anything else. Nevertheless, guesses have to be made, or no one would ever build a bridge or a factory. The economist can claim to be examining relevant material for what population is going to be able to live in a given area, when he studies the industrial potential of that area.

But all areas are interconnected. So the economist must construct—or forget to construct and assume—a world view. For this reason, economists are beginning to take much more interest again in the relationship in historical periods between population growth and economic development.

But when the economist attempts once more to bring population factors back into his thinking, he no longer expects to find any single overriding interrelationship between economic growth and population change. Both *a priori* reasoning and empirical study, inadequate as they are, suffice to disabuse him of this hope.

To give an example, the explosive growth in Europe's population has taken place at different dates in different countries, and there was by no means a simple correlation between the increase in the different countries and the increase in their industrial employment or their degree of urbanisation. In some cases population increase ran ahead of industrial employment opportunities; in other cases labour had to be imported. Over-rapid growth, in relation to employment, in some countries, is a

matter of twentieth-century history, while in others a phase of this kind occurred earlier. There has been no tidy relationship. Yet there *has* been an undoubted tendency in the inter-war years in Europe, presumably due to the pressure of demand for jobs, for industrial output to grow faster where the population pressure has been greatest; and there *has* been a tendency to note that in those countries where urban development has stagnated, this has been one cause of the failure of the economy to maintain a high level of investment and employment.

In other cases, the chain of causation may have worked the other way. The barriers to development may have been failure to invest rather than particular difficulties circumscribing urban development. Never before has there been such full and careful documentation available of the different rates and types of industrial growth and of the corresponding population changes. In consequence the diversity of means of growth is coming to be more fully understood. But much more remains to be done in these fields. We know some, but by no means all, the reasons why there is an economic advantage in living in cities, and there are great and fundamental difficulties in both constructing the conceptual formula to measure those advantages and in getting the necessary facts.

To give an example, based on the analysis of the distribution of labour between different occupations: the percentages of total labour employed in agriculture, or in the service industries are commonly used, the one negatively the other positively, as rough-and-ready indicators of the relative state of development of an economy. But there are notorious exceptions to any correlation of this kind: some very wealthy countries still retain a fairly high percentage of workers in agriculture, and some relatively poor countries carry more labour in service industries than they can very profitably employ there. Changes in the distribution of, as in the total of, employed population cannot be simply and directly correlated with economic progress.

There is the problem of defining the growth of a city, and of measuring the losses or gains due to shifts from a household to a market economy.

Before leaving this question of empirical studies, I think that I should say that while a great deal of new material is now available, from international agencies and one or two national research institutes, there is far too little done in the way of comparative study. For instance, it would be interesting to know more about the economic reasons for the extraordinary rates of population growth experienced in the state of California in the 1920's (66%), and again in the 1940's (53%), to have an explanation of its high birth-rate today, and to compare these changes with contemporary Australian developments. These new, and on the whole very successful communities, are not only interesting in themselves, but have grown in the face of all sorts of difficulties in the way of capital import and of employment adjustment. They may provide lessons for other communities. They may offer economists frameworks for testing their hypotheses.

Most economists are now aware of the importance of population change in relation to labour supply. Those who prefer to leave explanations of population change to other disciplines are treating that change as determined by non-economic forces altogether—as exogenous instead of endogenous to their model, as it is sometimes put.

Another equally serious omission is the complete disregard of the demand for children as part of the normal demands of human beings. One French authority on population has headed his chapter on technological progress 'Les Hommes, Sont-ils nécessaires?' In a rather wider sense, some economists have tacitly assumed a negative answer. Models might be constructed to show the demand for children, worked out on some plausible hypothesis, in relation to a family spending-unit's total demand over a period of years.

Some models, indeed, already have been worked out which try to treat population as an economically endogenous variable, that is as varying with changes in some

appropriate economic quantity. These models sometimes are worked out on the implicit assumption of a demand curve for children as incomes vary. More often they are quite general, and assume, but do not attempt to explain, changes in behaviour with regard to parenthood as incomes vary. That the model builders are right to experiment with the consequences of these possible economic relationships seems to have been borne out by the few elaborate enquiries made into motives for having children; one of the most famous of these enquiries, in which a team of social and other scientists were engaged, brought to light the point that economic and income factors were the only clearly distinguishable ones in deciding relative family size.

The model builders are to be congratulated too on their patient taxonomic contributions, because they are bringing out the variety of possible equilibrium rates of growth which an economy, even on slightly varying restrictive assumptions, may attain. The models are, and must necessarily be, couched in terms too abstract and rigorous and narrow to be applied to immediate current situations. But they nevertheless serve a very useful and practical purpose in flexing our intellectual muscles, and suggesting ways of thinking about the much more complicated actual real world; especially they draw attention to the narrowness of the assumptions required to justify the older classical system or its modern counterparts.

We know, from the models, that it is far from difficult to imagine a relationship between production, asset formation, income, and demand for labour which would imply, over a range, that employed labour must increase in size if income per head is to increase; we can imagine not only optimum positions in our models but equilibria at less or greater output than the optimum. Equally we can construct models to illustrate the effect, over a certain range, of diminishing returns, assuming certain scarce factors necessary to increased production.

So, while economists are still aware that, in certain carefully defined circumstances, and with the fulfilment of precise restrictive conditions, an increase in population (or a given rate of increase) is greater than that increase, or rate, which would have allowed that economy to maximise its production, they are not prepared any longer to conclude sweepingly that over almost any period a given representative worker and his family would be better off if the rest of the population increased more slowly than it actually did. This would beg the question of the interrelationship between the representative worker's employment and purchasing opportunities in the one case and in the other.

Economists have no simple message to deliver on population problems, but they are developing methods of analysis which enable them in the applied field, more readily to assess, than would be done otherwise, the forces at work.

Earlier, population theory was a central part of economics. It was seen as a clear-cut issue, and one universally applicable hypothesis was sought, adequate to cover all situations. The later neo-classical economists were more cautious, but they still included population in their field of discourse, and as part of long-term economic thinking. In the 'twenties and 'thirties of this century there was considerable vacillation of opinion as to the future of populations. It became the stigma of a lower order, a politician or journalist or someone of that kind, to be concerned with the possibility of overpopulation or underpopulation in the future. This period has now ended; and there is a wider recognition among economists of the importance of population, as is evidenced by both the empirical studies and the theoretical work that is now being increasingly devoted to population questions.

It seems that what is happening in the population field is only one instance of a change that is coming over economic writing as a whole. There is now a great need for international economic studies of various kinds, and applied economics in international fields has developed since the war; so have statistics of national income; and in consequence theory has a better empirical basis. There is even a discussion

of community indifference curves, or community demand, in unexpected quarters. Above all, both the theoretical and applied study of economic growth has flourished.

We probably shall not be led back, in population matters, to the classical theory, which is now seen to be applicable only to a special case. But we have clearly been led back to the perhaps unanswerable question which the earlier writers so heroically tried to ask themselves: Of what, in the last resort, is value? Perhaps now that we are aware of even more of the difficulties than they were involved in, in deciding how to answer this and similar questions, our views on population will gain in toleration and realism from their loss in dogmatism.

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INDUSTRY AND TECHNICAL PROGRESS

(Report of the Science and Industry Committee)

IT HAS for a long time been widely believed that British brilliance in pure science is not matched by enough speed and ingenuity in its industrial application. The belief is not fair to the best of British industry; but much backwardness remains, and a country so hard pressed in its economic affairs cannot afford to lose time in applying scientific and technical knowledge. With this in mind, the British Association, at its Belfast meeting in 1952, appointed a committee 'to study the problems of speeding up in industry the application of the results of scientific research', and it was joined in this work in 1954 by the Royal Society of Arts and the Nuffield Foundation. Generous support was available under the Conditional Aid programme, and the committee was able to set up research units at the University College of North Staffordshire and at the Queen's University, Belfast. The first fruits of the work is a book to be published by the Oxford University Press on May 31, under the title *Industry and Technical Progress* (by C. F. Carter and B. R. Williams; price 25*s*.).

The purpose of this book is to identify the things which help or hinder the application of science in industry. It is based in part on recent case-studies in British industry, and it fully confirms both the wide range of British industrial practice and the great changes in the attitude to science which have taken place of recent years. There are therefore no generalisations to be made about 'British industry', and no simple and outstanding causes of technical backwardness. The report suggests that technical backwardness is in fact commonly the expression of an attitude or habit of mind, which is shown also in other failings—for instance, secretiveness, poor management practices, ineffective recruitment policy and weak salesmanship. Twenty-four general characteristics, identified in technically progressive firms, were found to be usually absent in the unprogressive. The change from backwardness to progressiveness, therefore, is not usually just a question of removing an obstacle which stands in the path of a firm otherwise keen to move forward; it is a problem of changing the attitude and practice of the firm in many matters which cover a much wider field than its technique of production.

This does not mean that particular obstacles to speedier progress are of no account; their removal may be a necessary condition of advance, even if it is not a sufficient condition. The book discusses at some length problems of the availability of finance and the effects of high taxation, and, although it does not support some of the stronger claims about the financial handicaps of British industry, it tries to show just where these money matters may be important. There is also an examination of a shortage ultimately more crucial than that of money, the shortage of able and appropriately trained minds, and some questions are raised about the effectiveness of the British educational system and about the efficiency with which skills in short supply are used by industry. Other matters which might be considered as obstacles are looked at in the light of the evidence from the case-studies and from special investigations; for instance, restrictive practices, the small size of the British market, different forms of management and industrial organisation, and Government controls. Some of these do not appear to have great significance, and their elimination helps to concentrate attention on more important matters.

One of these is the importance of interconnections between firms in stimulating progress and spreading technical knowledge. Allied to this is the fact that technical progress may require the simultaneous advance of an interrelated group of firms, and the sluggishness of one may hold up all. Some firms are proud of their self-sufficiency; the most perfect vehicles for the communication of technical knowledge

pass them by, for they are not organised or equipped to reach out and take what is offered to them. Such parochial firms may cause delays far beyond their own industries. At the other extreme are firms in which research and development has found its proper place as a management technique, and which are organised to develop and use scientific advances, and to pull in new knowledge from all over the world.

The final paragraph of the text of the book refers to two findings, one encouraging, the other showing the magnitude of the difficulties which remain. 'We find that technical progressiveness is to some extent related to financial success, and in particular that it may pay to be first in the field, rather than to allow the pioneering to be done by others. If these findings are correct the forces of natural selection, stimulating the growth of profitable firms, are allied to those of technical progress. But on the other hand we suggest that backwardness is self-perpetuating, both in firms and industries; the backward firm, even if it can be made to desire technical progress, is ill placed to command the resources (and in particular the human ability) necessary to begin that progress. It will take much ingenuity by industry and government to break up the crust of habit and to divert lively and able minds from the places where change is most likely to those where it is most needed.'

CLIMATOLOGY APPLIED IN THE SERVICE OF MAN

FOLLOWING on the Presidential Address on the Use and Misuse of Climatic Resources (*The Advancement of Science XIII*, No. 50, pp. 56–66) Section E (Geography) devoted the whole of Monday, September 3, 1956, to a series of papers designed to show some of the ways in which the study of climatology can make a useful and practical contribution to the all-important matters of health, efficiency, productivity, and economy of resources. The morning session was devoted mainly to temperature and atmosphere pollution, each paper giving rise to a discussion which, unfortunately, had to be kept brief. The afternoon session was more closely confined to the water balance of the atmosphere and the soil and was followed by a long discussion to which members from other Sections made contributions.

Professor Gordon Manley examined the causes of fluctuation in the demand for fuels and, from an analysis of climatic records since 1700, showed how the rise and fall of consumption might to some extent be anticipated. Mr. M. Parry, examining the local variations of climate in certain built-up areas, demonstrated the effects of mean temperature and wind-strength on the heating requirements of buildings.

Dr. Alice Garnett dealt with atmospheric pollution and, choosing Sheffield itself for illustration, showed by maps of the distribution of smoke, soot, etc., how this is related to the relief and climatic conditions of the city site.

Miss E. M. Frisby gave examples of ways in which an advisory climatic service can help engineers, agriculturalists, industrialists and others, who, by planning their activities in accordance with climatic and meteorological circumstances and long- or short-term forecasts, can effect considerable economies and avoid disasters.

The afternoon session was opened by Mr. G. Melvyn Howe, who showed maps of the estimated water need, mainly for agriculture, in England and Wales. The converse, namely the supply of water, formed the subject of Mr. S. Gregory's paper. He reviewed the available material for assessing rainfall, run-off and storage, and showed that rainfall is only one aspect of a wide-ranging and involved problem. Professor B. J. Garnier dealt with the quite different condition of a tropical climate, examining the balance between rainfall and evapotranspiration in Nigeria with a view to indicating areas where climate favours irrigation development.

Mr. J. L. H. Sibbons critically examined the existing methods of calculating potential evapotranspiration on theoretical grounds, and, finding them unsatisfactory in certain respects, suggested a method of his own.

The discussion served to emphasise the need for even more intensive research into the mechanism of water transfer from soil to atmosphere and the estimation of the extent of water need, especially by crops, under varied conditions of climate in different parts of the world. The success or failure of agriculture, the need for and extent of supplementary irrigation, the extension of crop areas and the forecast of yields are all dependent on the accurate and reliable assessment of the water balance. Immense practical importance attaches to this field of study which invites co-operation between specialists of many sorts, physicists, meteorologists, climatologists, plant physiologists, agriculturalists, geographers and engineers.

The following account of the symposium has been prepared by Prof. A. Austin Miller, President of Section E (Geography) at Sheffield, and Head of the Department of Geography at the University of Reading.

CLIMATIC FLUCTUATIONS AND FUEL REQUIREMENTS

By Prof. G. Manley
(*Bedford College, London*)

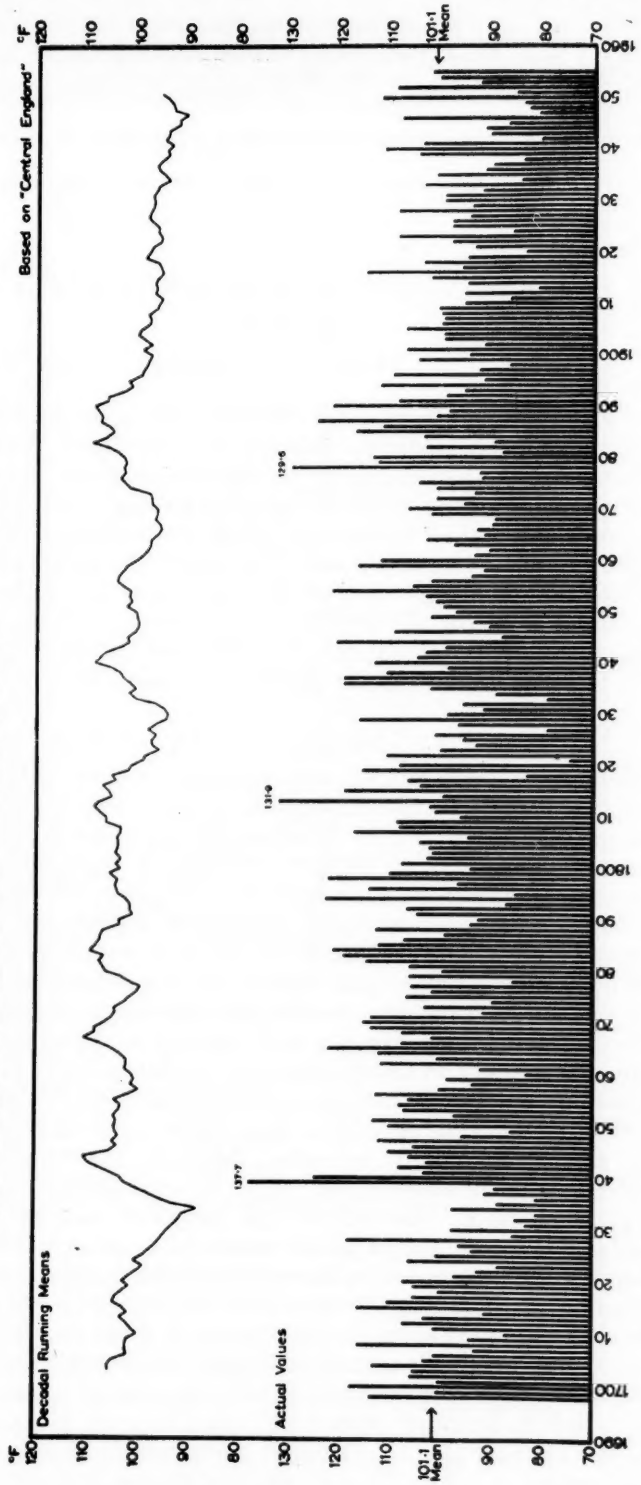
Apart from food, coal is our principal source of energy, and we no longer produce enough for our needs. Our fuel import, expressed in terms of coal, is now about 4 per cent of our production. Of the latter, about one-third goes to provide domestic, office and factory requirements of energy for lighting, cooking and heating. It is here demonstrated that the range of the variation in the demand for fuel for heating is about equal to the amount we import. Hence a summary of the chances of variation in the overall temperature of the 'heating season', September–May, is desirable. Accumulated totals of 'day-degrees' below 60° have been widely used as an index of the variation of the heating demand from one season to another. Here it is shown that in any year the total of 'month-degrees' below 57° is likely to provide a valid index which enables a summary of past vicissitudes to be presented, covering upwards of 250 years. To do this, use has been made of the table of monthly means representative of 'Central England' (Manley, 1953) which are in close accord with the averages for 'England and Wales' compiled by the Meteorological Office and beginning in 1901. If past vicissitudes are to be studied, especially those of the late Victorian era, the longer the period the better.

The diagram provides a summary of the incidence of variations in what we may call the 'interior-heating load' based on the above-mentioned table (in which 56°F. is approximately equal to 57° at sea-level). For each 'heating-season' the sum of the month-degrees is taken, and it will be apparent that the picture presented is one of wide and erratic variations. With an overall mean of 101, the range is from 74 in the mild winter and spring of 1821–2, to 137 in 1739–40 and 130 in 1878–9. No obvious pattern presents itself, even when we smooth the values in the form of decadal running means. The extreme range of the fluctuations appears tolerably constant.

The possibilities represented by seasons such as 1878–9 are manifest; between then and 1895 the 'heating demand' in several seasons stood 30 per cent above the present average, that is far above any during this century, in which 1916–17 ranks as the most demanding 'cool season'. On account of the tendency for milder weather in autumn and spring, the average characteristic of the last three decades has come down to 94. It is evident that heating demand is not merely a result of the more dramatic severe spells in winter. Cold springs are probably more significant; the long cool season of 1950–51 set up a greater demand for warmth than the notorious 1946–7. For many years past, since about 1925, the majority of the autumns and springs have been warmer than was characteristic of some earlier decades. Should a recession develop, with a tendency for colder weather in the spring months, the effects on fuel demand will be noteworthy.

I have to thank officials of the Coal Board for opportunities for discussion. From such comparisons as I have been able to make with the results of statistical investigations of the rate of consumption of coal carried out by Dr. Daniel, of the Ministry of Fuel and Power, to whom I am much indebted, it appears that a rise of 30 per cent in the accumulated temperature deficit in any one season is likely to result in an additional requirement of between five and seven million tons of coal. We may also note, from the diagram, the suddenness with which severe seasons may arrive, e.g. that of 1739–40 following a series of mild seasons for which the evidence is well attested. That of 1878–9 also befell with little or no preliminary warning.

The problem of seasonal forecasting is as yet unresolved and as yet we can merely place the fluctuations on record, drawing particular attention to the erratic



THE SEASONAL VARIATION OF THE 'INTERIOR HEATING REQUIREMENT' SINCE 1700
ACCUMULATED DEFICITS IN MONTH-DEGREES BELOW 56°F.

A departure of 30 month-degrees corresponds with a change in total coal consumption of 5 to 7 million tons under present-day conditions. The peaks in 1916–17, 1940–41 and 1950–51 are much below those of the Victorian era. Main deficit 1921–50 = 94°.

incidence of that most trying combination of a severe winter and a cold spring. Further research on the causes of these minor fluctuations is desirable, as they directly affect the nation's energy balance.

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LOCAL CLIMATES AND HOUSE HEATING

By M. Parry

(*University of Reading*)

The heat loss from dwellings—and therefore the heating required to maintain comfortable indoor temperatures—depends on controllable factors like the design and dimensions of the house and also on the uncontrollable factors of the external climate. Paramount among these are temperature and wind force: the difference between inside and outside temperature partly determines the rate of heat loss by conduction through the exterior shell of the house; the wind speed affects the heat lost as a result of ventilation (air change). This paper examines some recent local climatic studies from the standpoint of the heating and ventilating engineer by attempting to assess the differences in heat loss (and heat requirement) attributable to local factors such as relief or the presence of a built-up area.

Local Variations in Degree-days

The temperature factor is conveniently expressed in terms of heating degree-days, i.e. accumulated temperatures below a base of 60°F.; this is 5° below the desirable comfort temperature of 65°F., the difference being accounted for by solar and other incidental heat gains (Dufton, 1934–5). The annual degree-day total is a measure of a large part of the heating requirement of a building (particularly where the wind speed is low, e.g. in built-up areas). Strictly, it applies only where a constant indoor temperature of 65°F. is maintained, i.e. with central heating. With the more intermittent heating usual in most homes, the relationship is less close, but the degree-day values still bear some proportion to the actual heating requirements.

The results of three local temperature surveys lend themselves to conversion into degree-days: firstly, in the Reading district (Parry, 1954, 1956), one of modest relief including a moderately sized town (120,000 people); secondly, in the Nottingham district (Tinn, 1938), in which a larger town (some 280,000 people) occupies an area of greater and more varied relief; thirdly, in the Bath region (Balchin and Pye, 1949–50), with the smallest town of the three (80,000) but offering a considerable range of elevation. Maps have been prepared showing degree-day values (expressed also as percentages of that at one station in order to facilitate comparison) plotted against the background of the relief and the built-up area (Figs. 1, 2, 3).

Examination of these maps reveals that the extra warmth of the urban area results in sites within the town generally having 5–7 per cent less degree-days than nearby rural sites at similar elevations. There is always difficulty in obtaining an urban site that is truly representative of the most closely built-up part of the town, but one station in Reading, deliberately used because of its oversheltered site, falls into this category (Fig. 1). If this is characteristic, then the heart of the town has an advantage of up to 10 per cent less degree-days than the surrounding country. A 10 per cent difference in heating requirement is equivalent to something like half a ton of coal a year for an average house.

In the Bath area, the high plateau station (at 720 ft.) accumulates 16 per cent

more degree-days than a low-lying urban station (at 65 ft.) and 10 per cent more than a valley station (at 125 ft.) outside the town; this represents an increase of about 55 degree-days per 100 ft. of ascent.

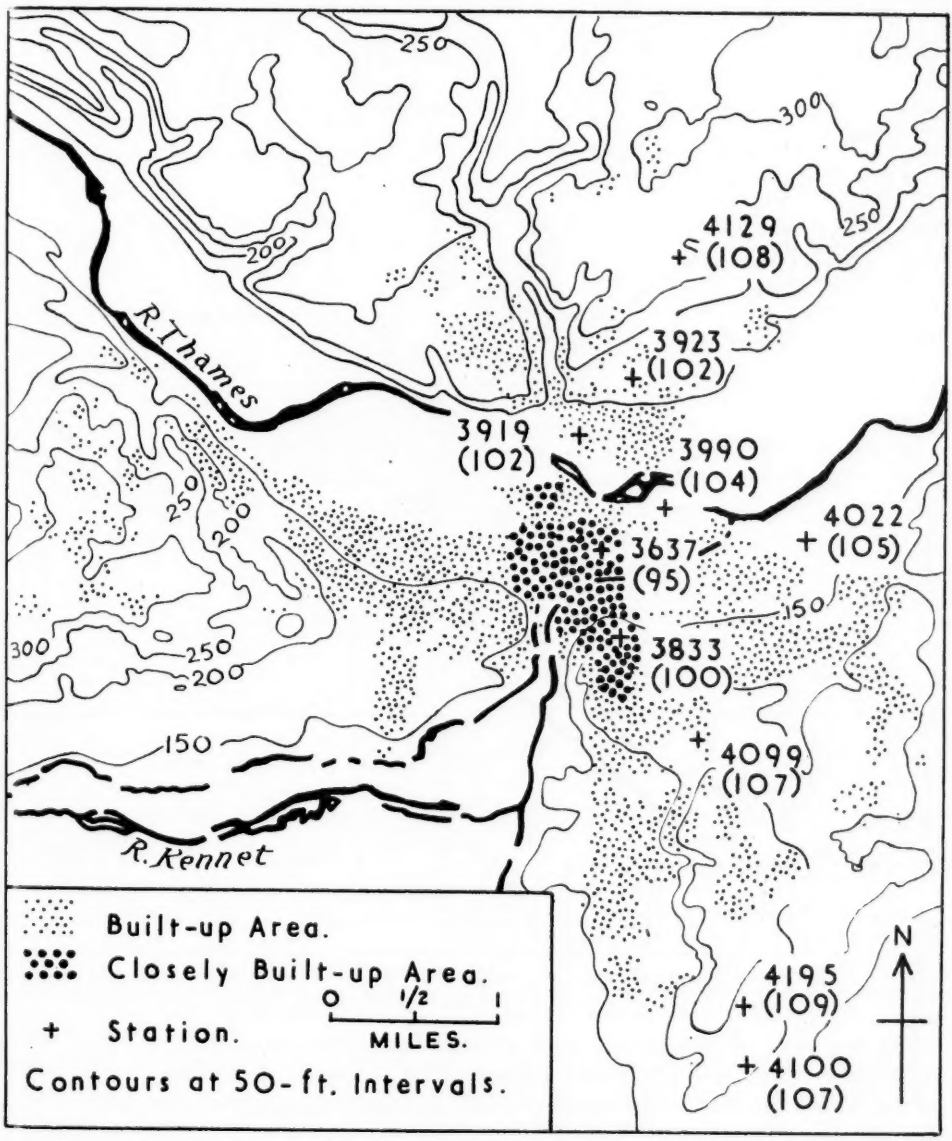

Fig. 1.—Degree-days below base 60°F. in the Reading area, for the twelve-month period December 1951–November 1952. (Percentage values in brackets.)

Wind Speed and Air-change Rate

Increased wind strength speeds up the rate of air change through a house and therefore the heat loss due to ventilation. The effect of wind thus reinforces that of temperature since wind strength increases with elevation and is greater outside the town than within. Little information is available regarding local variations in wind force, and use is made here of limited data from the Reading area (averages of Beaufort Scale observations made daily at 0900 G.M.T.) in an attempt to give an approximate idea (no more is possible) of the combined effects of temperature and wind.

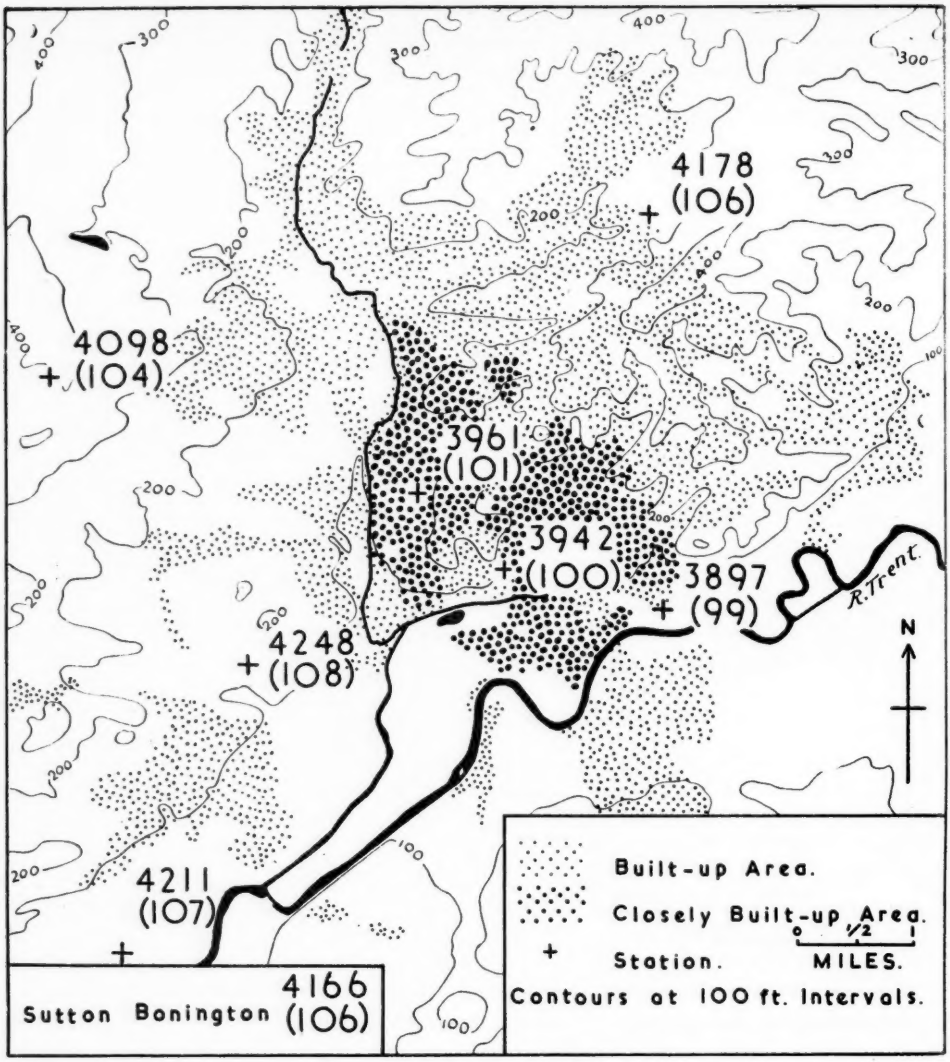

Fig. 2.—Mean annual degree-day values (base 60°F.) in the Nottingham area, mainly for the period 1928–36.

On the basis of comparison with average figures for diurnal variation of wind strength at four low-lying inland stations (Kew, Oxford, Mildenhall, and Parc St. Maur, Paris) the 0900 wind speed can be assumed to exceed the mean wind of the day by about 10 per cent. The Reading 0900 averages were therefore reduced by this amount.

It is not possible to establish a general relationship between mean wind and average rate of air change, since the latter must depend also on the size and design of the house and on highly variable factors like the window-opening habits of its occupants. A very thorough investigation of the ventilation of occupied houses has been carried out at the Building Research Station's experimental site at Abbots Langley (Dick and Thomas, 1951). From data obtained, a graph was prepared relating wind speed and rate of air change for a uniform type of house and assuming average window-opening habits.

Converting the Reading wind values into air-change rates in this way, and using the annual degree-day values, it was possible to calculate, for ten stations, the heat

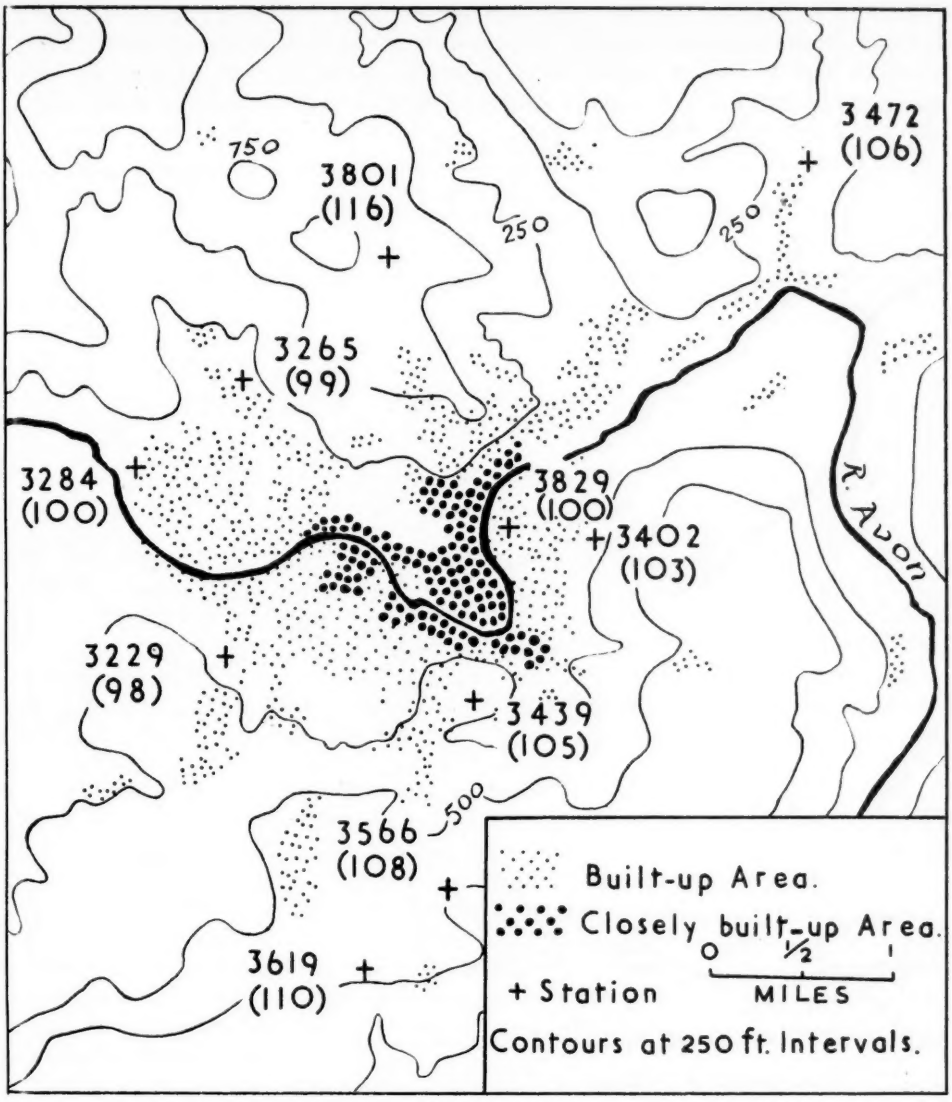

Fig. 3.—Degree-days (base 60°F.) in the Bath area for the year 1945.

loss (or heat input required to maintain indoor temperatures of 65°F.) over a twelve-month period, by means of the formula

$$(A_1 U_1 + A_2 U_2 + \ldots) \times 24 \times D \quad \text{(conduction heat loss)}$$
$$+ VD \times 24 \times 0{\cdot}019 \times N \quad \text{(ventilation heat loss)}$$
$$= \text{total heat loss in B.Th.U. (divide by 100,000 to convert to therms),}$$

where A_1, A_2, etc. = area of walls, floor, etc. (ft.)
U_1, U_2, etc. = thermal transmittance appropriate to A_1, A_2, etc. (B.Th.U./sq.ft./hr./°F.)
D = annual degree-day total
V = internal volume of dwelling (cu. ft.)
N = number of air changes per hour
$0{\cdot}019$ = number of B.Th.U.'s required to raise the temperature of 1 cu. ft. of air through 1°F.

All this necessarily assumes a uniform type of house, but values have been chosen for size, area of walls, etc., and '*U*' values (thermal transmittances) for these external surfaces that would be appropriate for a representative type of post-war local authority house (I.H.V.E., 1942). The local climatic factor can be isolated only by assuming that other things are equal.

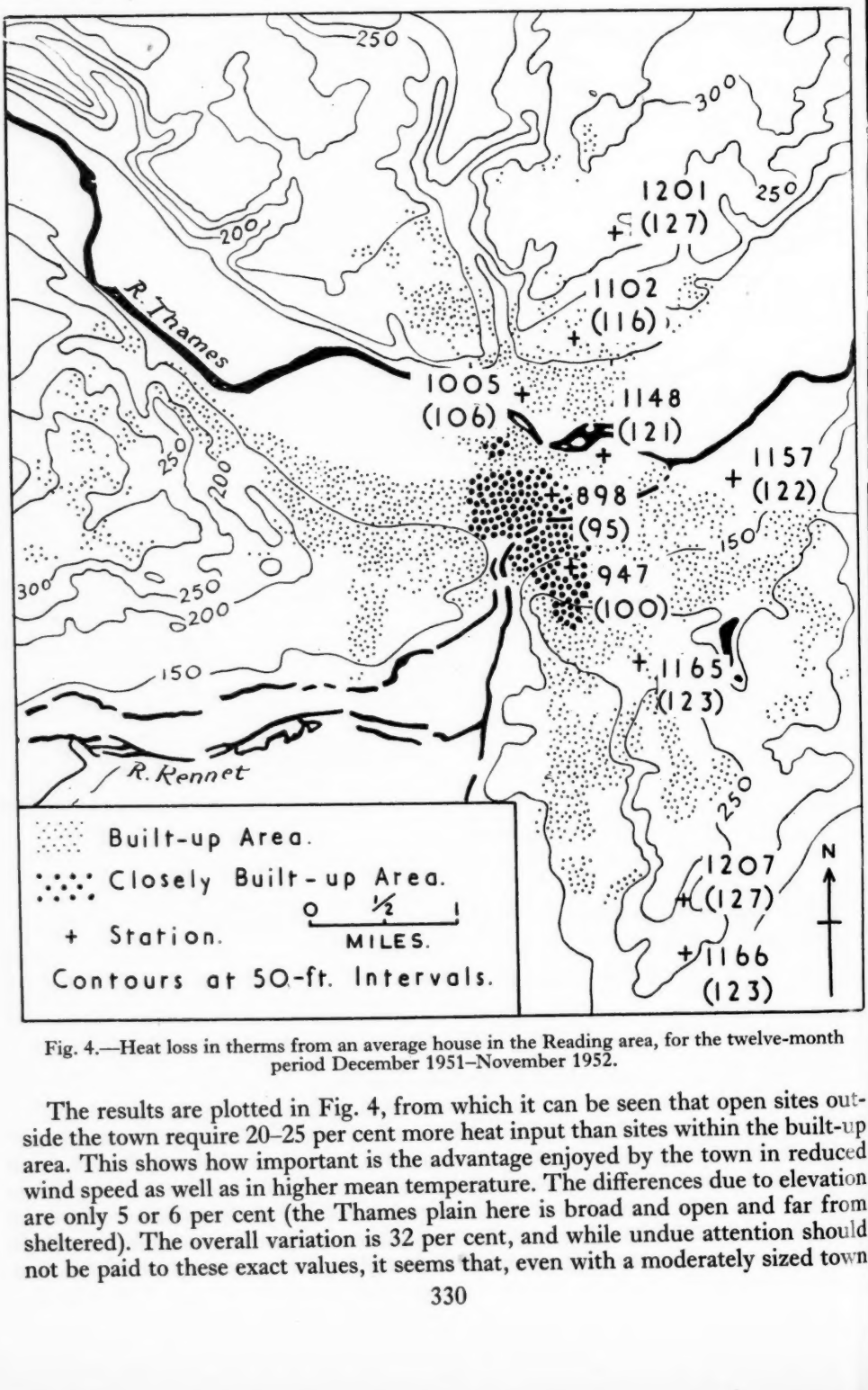

Fig. 4.—Heat loss in therms from an average house in the Reading area, for the twelve-month period December 1951–November 1952.

The results are plotted in Fig. 4, from which it can be seen that open sites outside the town require 20–25 per cent more heat input than sites within the built-up area. This shows how important is the advantage enjoyed by the town in reduced wind speed as well as in higher mean temperature. The differences due to elevation are only 5 or 6 per cent (the Thames plain here is broad and open and far from sheltered). The overall variation is 32 per cent, and while undue attention should not be paid to these exact values, it seems that, even with a moderately sized town

in an area of subdued relief, local variations in heat requirement of 20–30 per cent may be expected.

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CLIMATE, RELIEF AND ATMOSPHERIC POLLUTION IN THE SHEFFIELD REGION

By Dr. Alice Garnett

(*University of Sheffield*)

The distribution and nature of atmospheric pollution is, fundamentally, a matter for geographical study, in three important respects. It is concerned, firstly, with a product of the 'force of human activity' supplied to the atmosphere in varying amounts and forms by man; it is, secondly, distributed within this medium in accordance with the physical laws dictated by the local and regional meteorological and climatic conditions; and, thirdly, this distribution may be further modified in varying degrees by the influence of surface relief. In the Sheffield region the effects of these three relationships are clearly evident.

The pattern of the relief of the urban site (Fig. 1) is striking. The Don valley makes a sharp elbow turn through the heart of the city. Above this bend the upper valley is deeply incised into the Pennine hills, to give, for a large industrial city, a narrow valley with unusually steep sides orientated from north-west to south-east, and sunk from 300 ft. to 700 ft. below the adjacent plateaux and spurs. Tributary valleys of even bolder form enter from the west and south-west. In the heart of the city commanding spurs from both north-west and south-east narrow the valley at the elbow turn, but below this, the Don valley continues as a broad and shallow trough of much more subdued—though still distinctive—relief, opening from south-west to north-east.

In relation to climate, the nature of this relief is significant, whether considered in relation to vigorous unstable air circulation flowing across the region, or to calm and stable air masses lying stagnant over both hills and valleys. In the former case, the upper Don valley and its western tributaries act as natural conduits at ground level for prevalent north-westerly and westerly air circulation, to which the east side of the valley presents a continuous obstacle. The lower Don valley on the other hand lies open to the path of south-westerlies, and might be expected to be swept clear of pollution with favourable 'down valley' winds. In the second case, under calm anticyclonic spells of weather, both sections of the Don valley offer basins into which cold air will gravitate and accumulate, forming reservoirs of stagnant stable air favourable for fog formation. Inversions of temperature are commonplace (see *Sheffield and its Region*, page 53) during the winter months, and often in Sheffield they are clearly evident when fog develops in the colder valley bottoms, leaving the warmer higher suburbs bathed in sunlight. These valley fogs, though induced by relief and air drainage, are often intensified and much prolonged in duration by the effects of heavy sources of pollution within the valleys which provide prolific supplies of condensation nuclei.

The ultimate distribution of pollution (considered collectively over any area, and for a period of time) reflects not only the influence of relief and climate but also the distribution of urban functions on which the source of supply depends. Urban land use in Sheffield in relation to relief is illustrated in Fig. 2 for a major part of the city. The map demonstrates the location of heavy industry in the valley bottoms where other physical conditions are likely to favour the concentration of pollution. It also shows the role of the adjacent plateaux and spurs primarily for residential development, and hence sources of domestic pollution. Furthermore, the nature of the daily industrial cycle in Sheffield contributes to the problem in other ways, emphasising the significance of the valley sites; for the areas of heavy industry are generally associated with systems of work-shifts maintaining continuous production, day and night, and the nature and effects of the diurnal cycle of pollution from such sources will be different in the valleys from the cycle applicable to the residential areas on the adjacent spurs and plateaux. Let it not be forgotten, also, that pollution of the air by night shift-working contributes a quota during just those hours when, in relation to the mean diurnal cycle of atmospheric turbulence, the atmosphere is most likely to be stable, and therefore most favourable to the accumulation of impurities locally. During the hours of daylight, these might well be transported elsewhere, or widely diffused, under conditions of increased turbulence.

A pioneer attempt has been made to map for a period of two years the monthly records of pollution (SO_2 and solids) in relation to both relief and the monthly weather records of the local Air Ministry station at Weston Park. Not all of these maps can be included here, but a selection is shown in Figs. 3–8 to illustrate some of the features more generally evident; these are as follows:

1. Despite the differences, month by month, in the direction and strength of the air circulation, centres of heavy pollution tend to develop and to persist in two conspicuous areas. One lies over the valley floor not far below the bend of the Don. The second is within the upper Don valley, but in this case is located upslope, against the east valley wall, and sometimes it encroaches over the summit on to the plateaux.
2. Periods of more stable air conditions or of very light circulation and calms show a widened area of comparatively marked pollution (for both SO_2 and solids), but the main Don valley centre at such times does not invariably show tendencies towards a much heavier concentration of pollution, though the air for the region as a whole is more heavily polluted.
3. The 'upslope' eye in the upper Don valley changes in shape and intensity, with changing directions of air-flow, but the pattern only shifts towards the valley floor when the air circulation is predominantly from the north.
4. Vigorous circulation does 'clean' the regions, in some degree, but it does not appear materially to move the lower eye of heavy pollution 'down wind', nor to weaken very markedly its concentration, by stronger diffusion at such times.

It is hoped that facilities will be found for an extended and more intensive survey based on the daily readings of a greatly increased number of stations more widely dispersed over the Sheffield area, for it would appear that, in its site, climate and industrial pattern, Sheffield offers unique opportunities for an investigation of this kind.

ACKNOWLEDGEMENTS

I am indebted to Mr. R. S. Waters, M.Sc. (Exeter Department of Geography), for considerable help in the collation and initial plotting of data concerned with atmospheric pollution; to Mr. A. J. Hunt, B.A. (Sheffield Department of Geography), for the mapping of urban functions; and to Mr. Barwick (Sheffield Museum, Weston Park) for assistance in the provision of meteorological data.

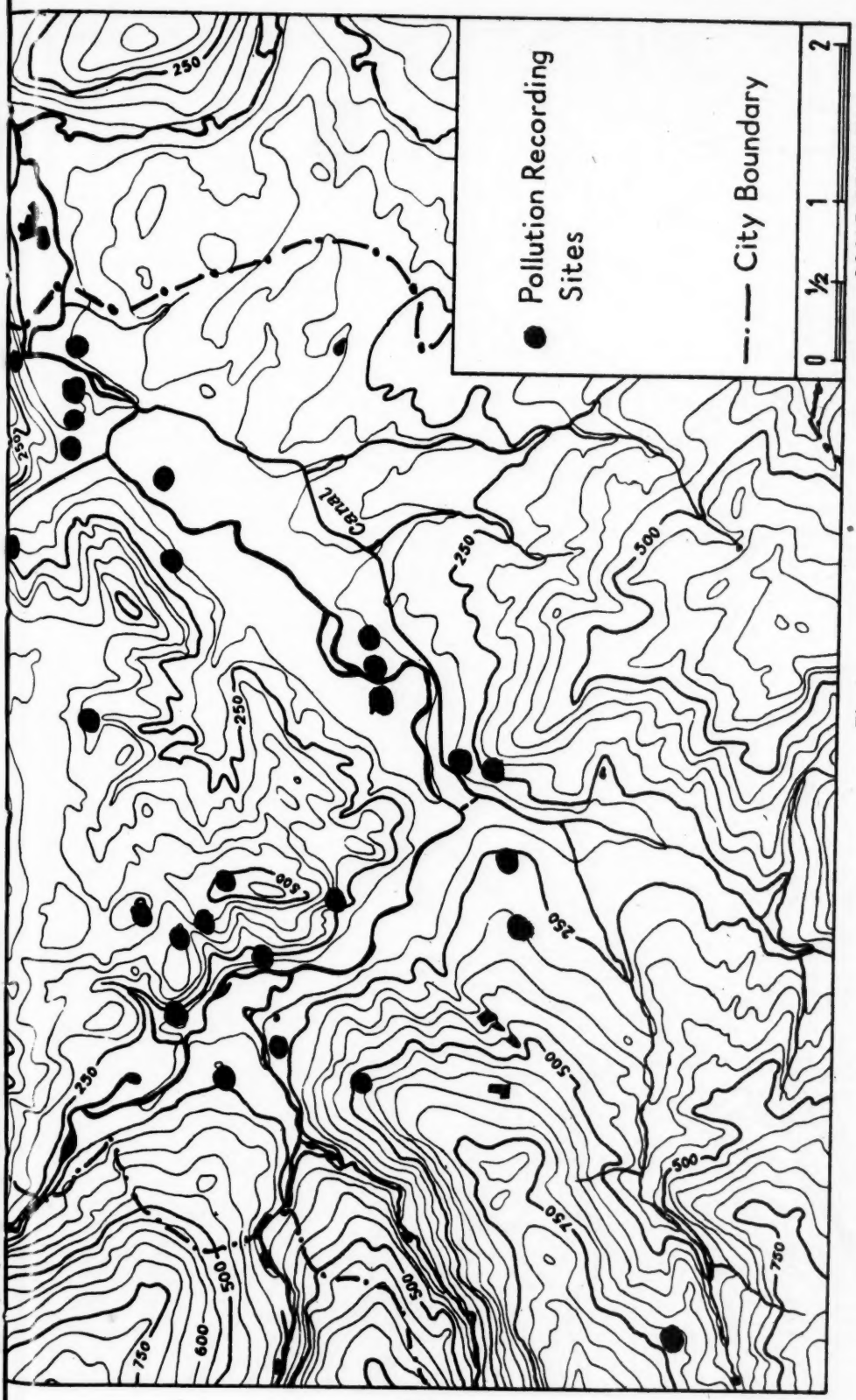
Pollution Recording Sites
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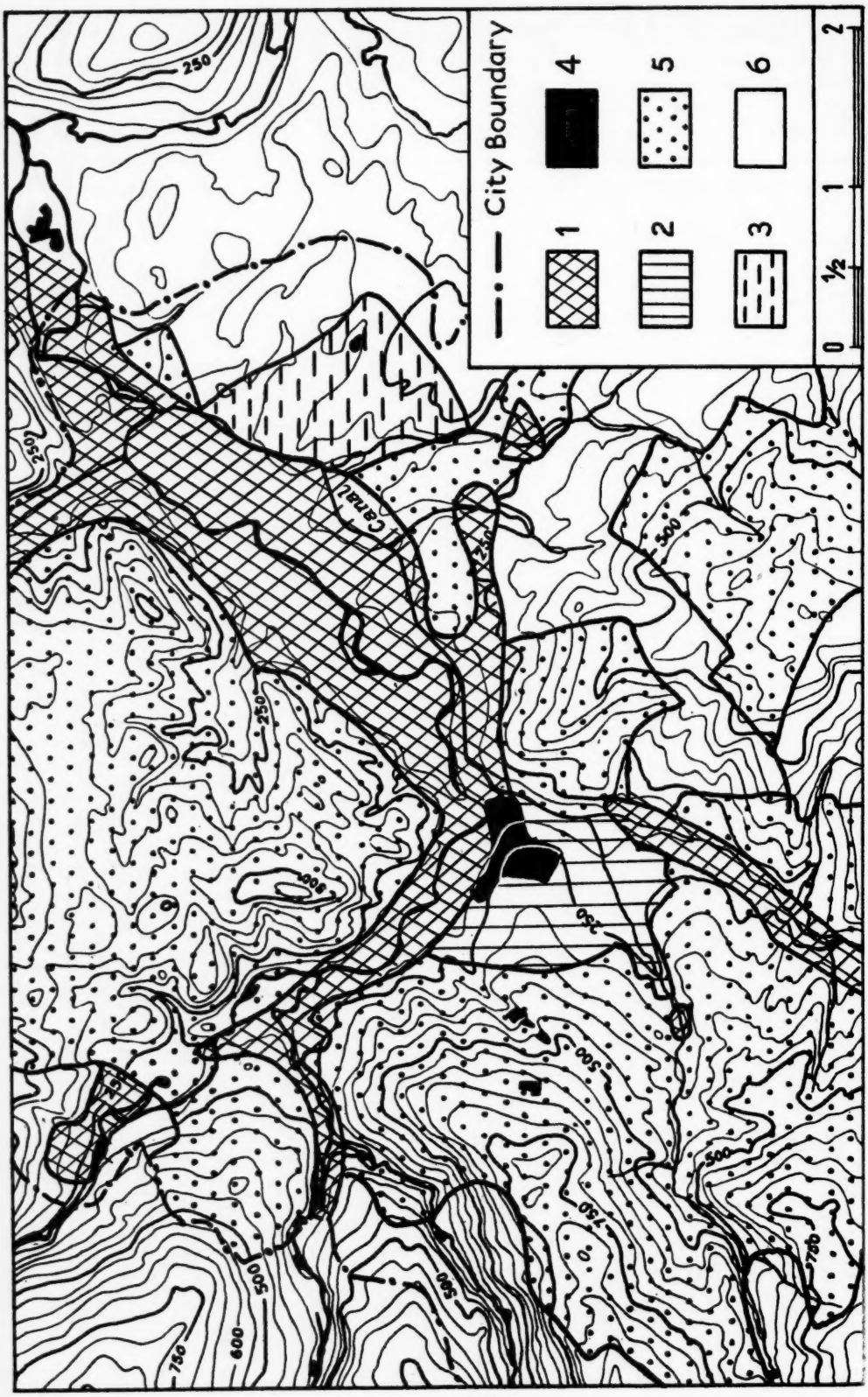
Fig. 1.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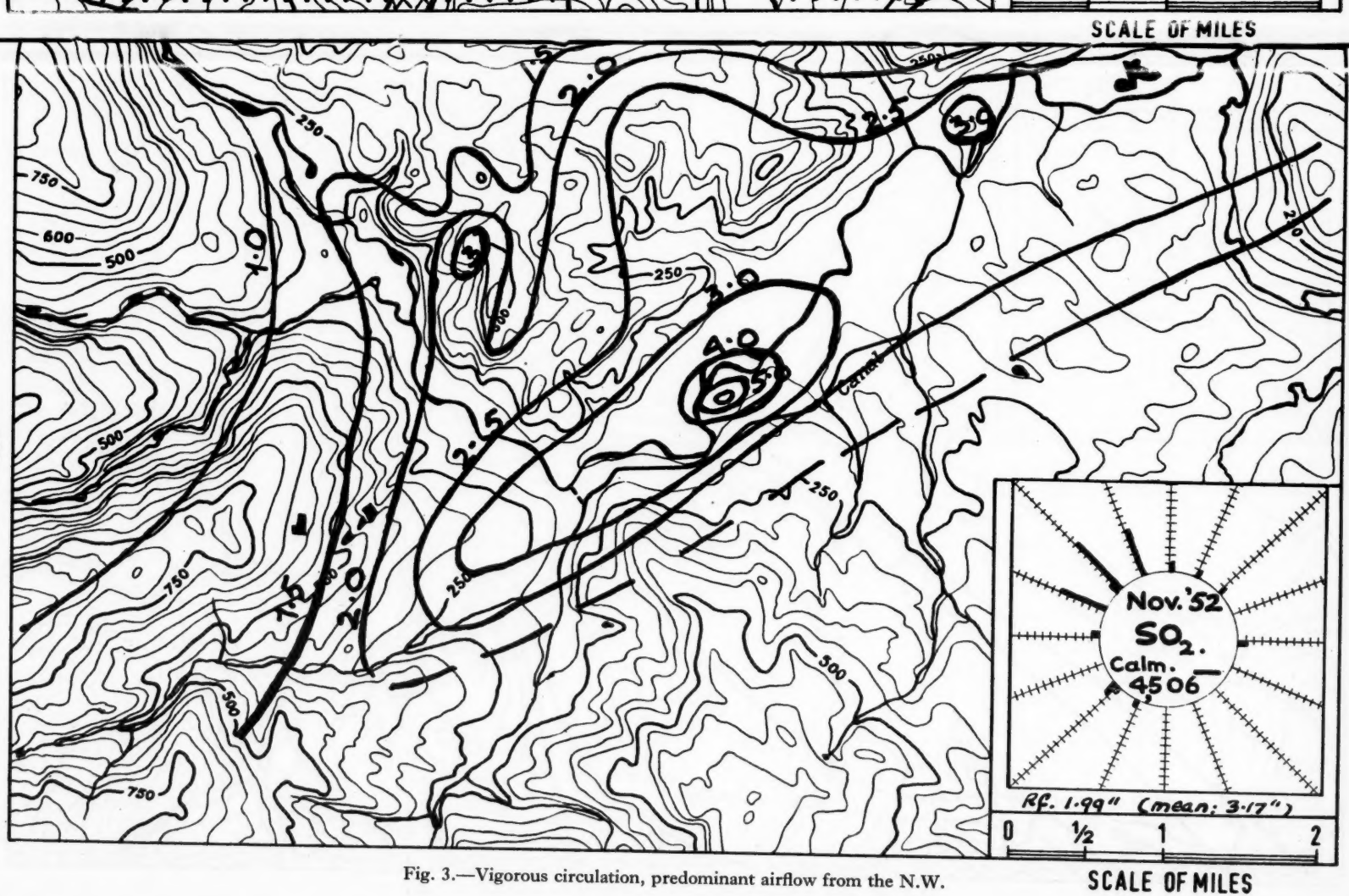
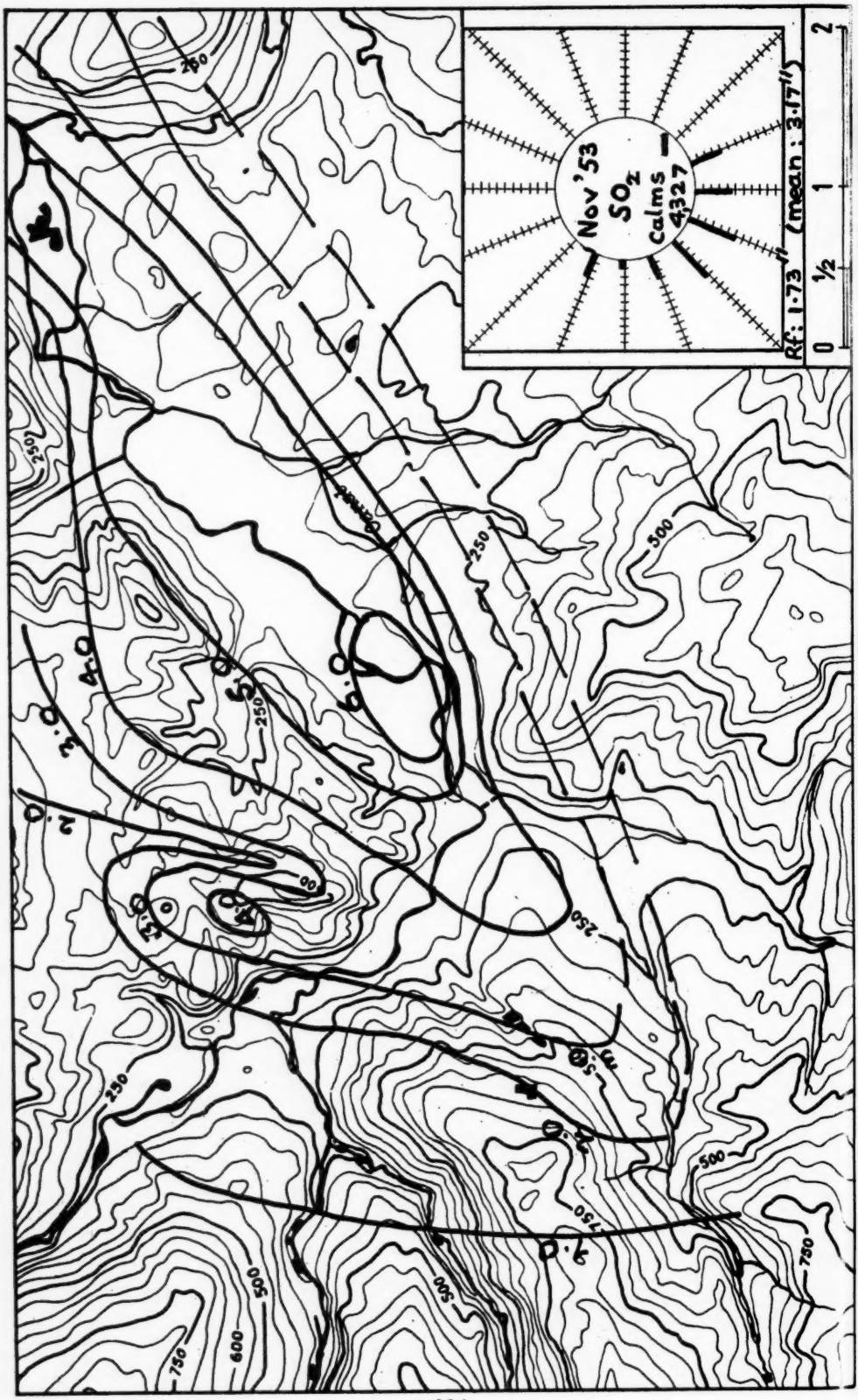


Fig. 3.—Vigorous circulation, predominant airflow from the N.W.


Nov '53
SO_2
Calms
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3·0
4·0
5·0
6·0
7·0
8·0
9·0
10·0
11·0
12·0

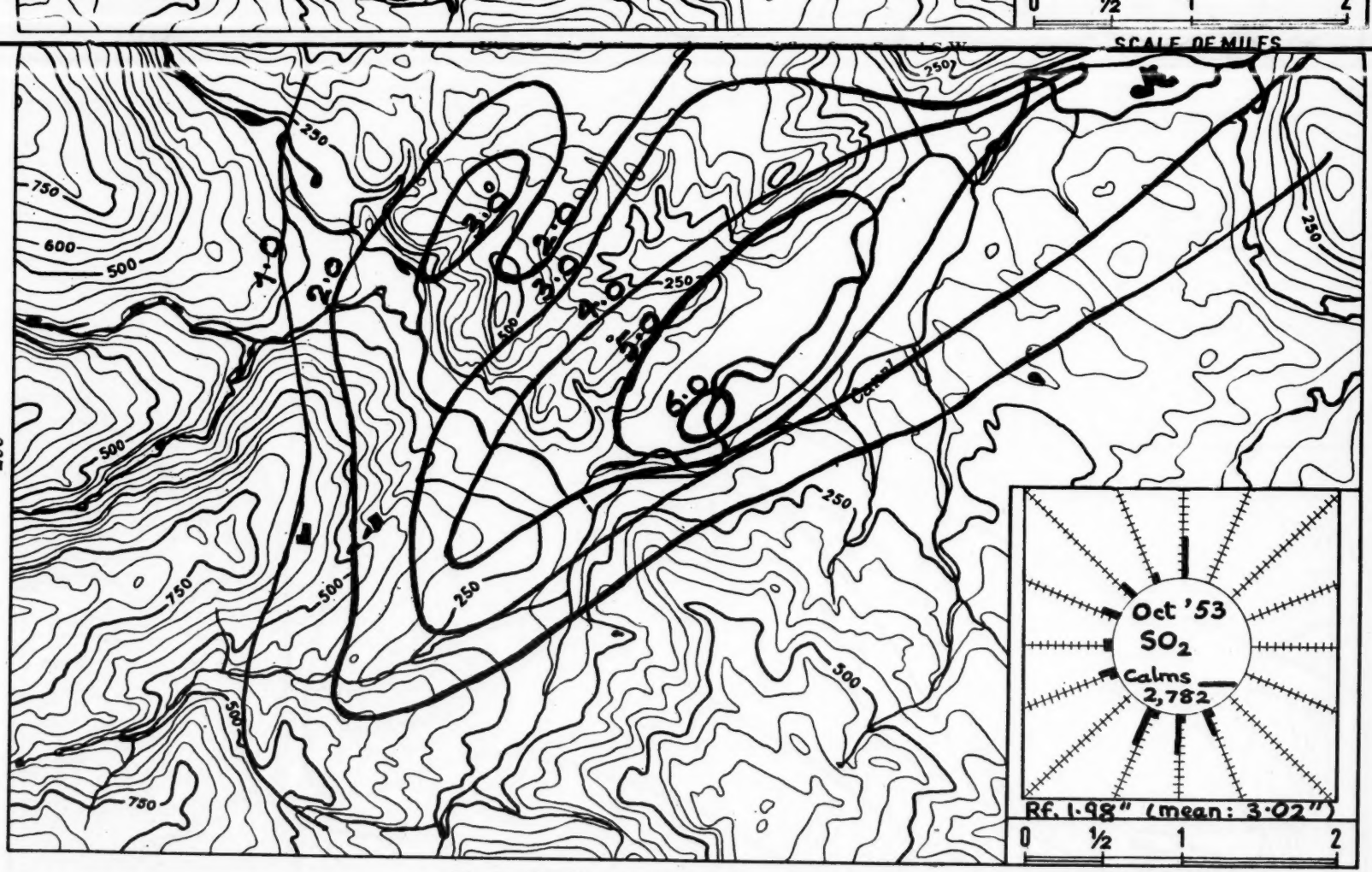
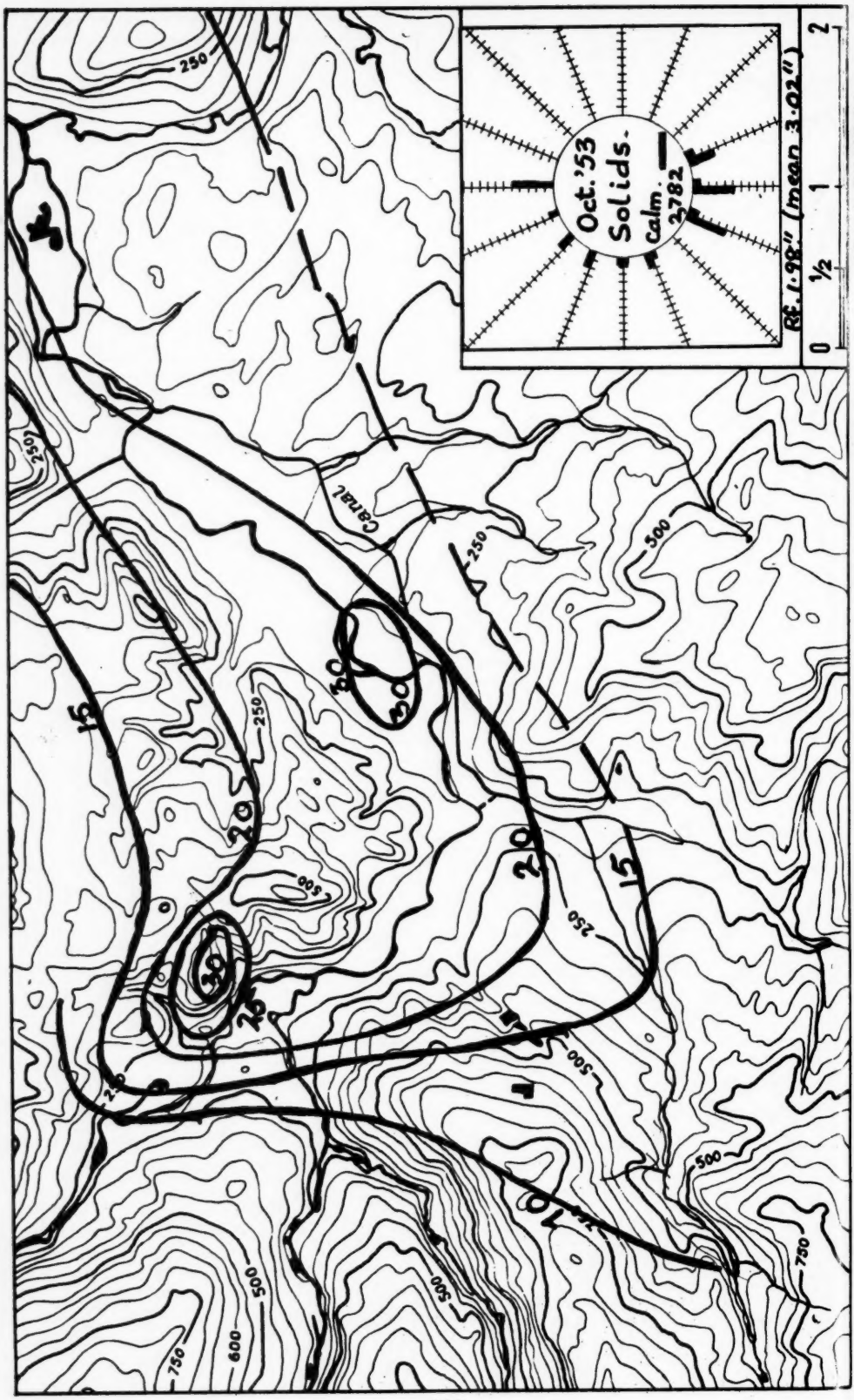


Fig. 5.—Very light circulation and considerable calms.


Oct.'53
Solids.
Calm.
2782
Rf. 1·98" (mean 3·02")
0
½
1
2
SCALE OF MILES
Canal
250
500
750
600
15
20
30

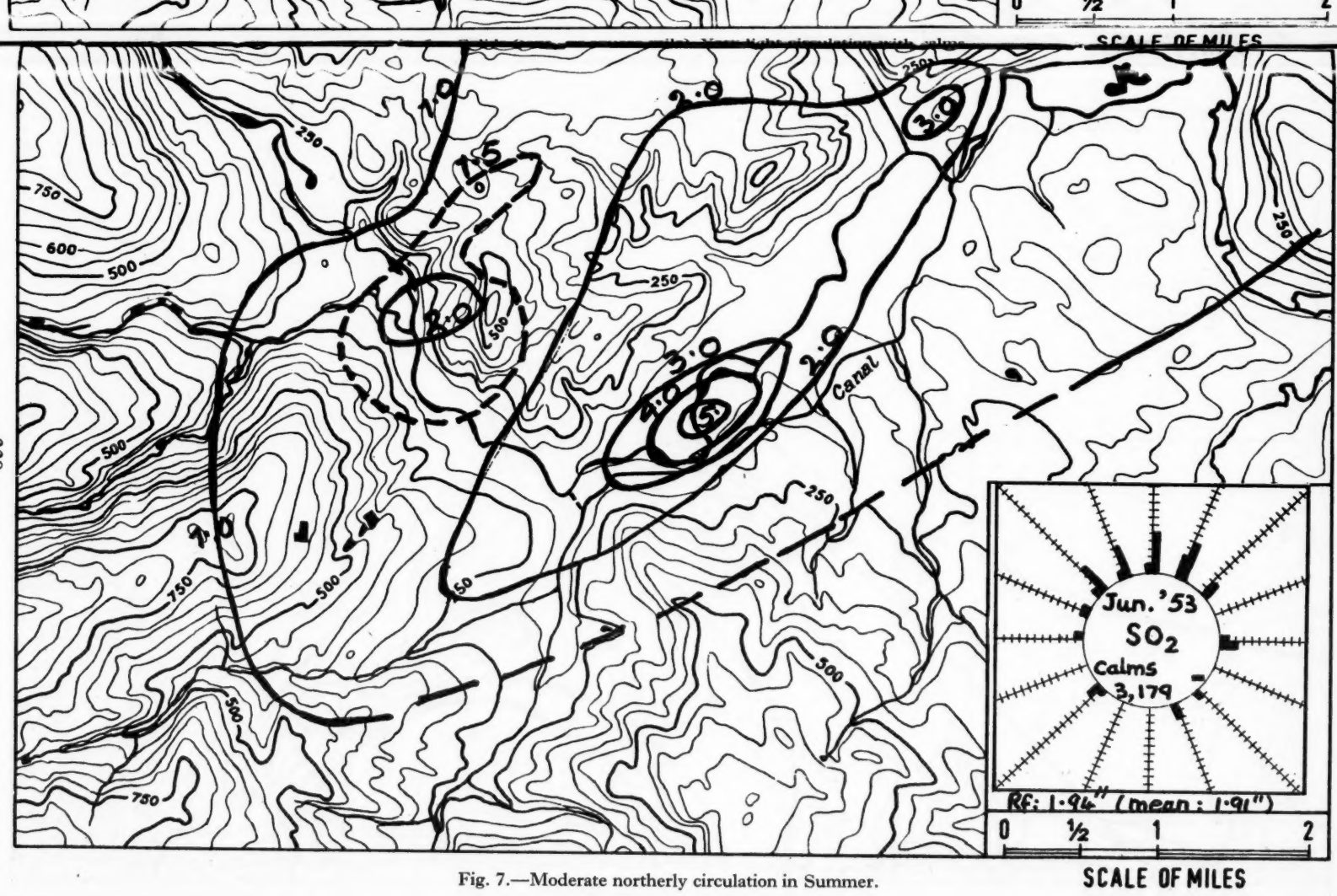


Fig. 7.—Moderate northerly circulation in Summer.

Jul.'53
Solids
Calm.
4,482
R.F.: 2·59" (mean: 2·6")
0
½
1
2
SCALE OF MILES
Canal
250
500
750
600
10
15
20
25
30

Key to Maps

A. *Pollution.* (1) SO_2 is shown by 'arbitrary units'—i.e. assessed from the mean rate of sulphation on 100 sq. cm. of 'lead peroxide candle' exposed for one month under standard conditions.

(2) Solids record deposits estimated as tons per square mile per month. (Records obtained from the monthly Atmospheric Pollution Bulletins of the Department of Scientific and Industrial Research, Fuel Research Station, London.)

B. *Weather Records.* The wind vane shows (1) number of days with the wind from a given direction; (2) number of days with calms (see horizontal line); (3) the number of days when air may be presumed to be fairly stable since the air speed was very low (shown for each direction by a shorter second line, when appropriate). (4) The total air mileage recorded for the month through the wind tube is also given, as a general index of the vigour (or otherwise) of the circulation. (5) The actual rainfall for the month and the mean for the month are indicated, since a dry month may give higher readings for SO_2 and lower for solids (because of the nature of the recording apparatus) than would be the case in a wet month (i.e. variations in amounts recorded do not necessarily only reflect variations in amounts of pollution emitted, or variations in meteorological conditions favouring diffusion or concentration of pollution).

WEATHER ENGINEERING IN THE SERVICE OF INDUSTRY

By Miss E. M. Frisby

(*Director of Climatology, American Institute of Aerological Research*)

This paper describes what is being, and has been done by the geographers and meteorologists of a specific research group in the States, over a period of twenty-five years, to aid certain industries in the solution of their weather problems. Single instances of weather services developed for a variety of different types of industrial organisation have been described, rather than a multiplicity of examples for any one industry.

The term 'weather engineering', possibly unfamiliar to a British audience, is one that is gaining increasing popularity in the United States. It describes the job of processing and manipulating synoptic and climatological data in the development of specific weather services geared to individual industrial operations. There are very few industries that are not, at some stage in their operation, faced with a weather problem. The ones most weather-sensitive were listed conveniently in the *Meteorological Magazine* of January 1956 in an article entitled, 'Progress in the Climatological Services', by Mr. H. C. Shellard, under the four headings, 'Building and engineering', 'Power supply', 'Transport and communications', 'Industrial research and development'. (1). The present paper endeavours to describe a weather service developed for a specific industry in two of these four groupings: under 'Building and engineering' is described pipeline construction; and under 'Power supply', the gas industry.

Weather Services Applicable to Pipeline Construction

As in the case of every weather service applied to industry, the weather engineer must be in possession of all the facts concerning his client's operation at those points at which weather exercises a controlling influence. Extreme care must be taken in the initial determination of critical conditions affecting a given operation or process of an operation. Many pipelines in the United States have been laid in country which was little known or entirely unknown to the crews sent to work them.

Many lines cross high and rugged country which can only be worked in certain months of the year. From the standpoints of construction-management, personnel well-being, and economy in construction time, there is every reason for preluding an operation of this kind with a climatological survey.

1. *The Climatological Survey*, then, is the first requirement, from which an estimate can be given of numbers of workable days for a specific month and for each section of a line—'workable' being defined according to the company's criteria. Here, as always, the emphasis is on not one, but a number of weather elements affecting operations coincidentally. For example, an operational day (say from 8 a.m. to 5 p.m.) involves experiencing less than one-quarter inch of rain, less than one inch in the previous two days, average temperature above 16°F., wind less than 30 m.p.h., and less than 6 inches of snow on the ground. This happens to be an overall assessment of workability—other surveys may be worked on criteria for specific phases of construction, namely, Trenching and Ditching, Coating and Welding, etc. All this can only be done by close association with the client group.

2. *Long-range Forecasts*. The next requirement, when the operation comes within forecast range, is a long-range weather forecast to sharpen the estimates based on climatology alone. It is impossible to discuss longer-range weather forecasts without passing reference to the method on which they are based. Briefly, North American weather is capable of rough categorisation in a recognisable and finite number of weather types. The cataloguing of a long historical record of these types, day by day, demonstrated the fact that weather history repeats itself in recurring rhythms of differing lengths. A study of these rhythms, combined with a knowledge of the forces that influence their periodicity and intensity, make long-range forecasts of successive weather types possible. Present weather sequences are matched against similar ones occurring in the past. Future trends are then developed on a probability and extrapolation basis.

Study of the precipitation and temperature anomalies associated with the weather types makes feasible the preparation of overall temperature and precipitation forecasts month by month, several months in advance. These are very useful guides for quick comparison of one area with another within the United States. Moreover, the 'weather type' approach to longer-range forecasting allows the preparation of forecasts, one month in advance, which detail wettest, coldest, and hottest periods within the forecast month. The 'timing' of expected spells of weather is at present outside the scope of any other longer-range forecast method than the one described.

3. *Short-range Forecasts*, using client terminology, supply the weather advices needed on a day-to-day basis when the operation gets under way.

Weather Services Applicable to the Gas Industry

In spite of universal recognition of the fundamental relationship between weather and gas load, and the need for quantitative forecasts of a type that can be of material assistance to the gas industry, such forecasts are rarely prepared. The various weather elements affecting load vary in their degree of effect over different sections of the country. For example, while temperature and wind are major parameters in Southern California, precipitation and cloud cover are additionally important factors in Colorado. Moreover, 'no two electric or gas companies are the same and each has its own weather-influenced variations in load and its own weather problems.' (2) Indeed, general rules governing weather/gas-load requirements are impossible of formulation over even quite small areas, not only because weather elements differ in their degree of effect on load from place to place, but also because every gas company has its own operational requirements and character, so that each unit of the industry is faced with a particular weather problem, differing from that of its neighbour.

The following types of weather service are now being used by a variety of gas companies in partial resolution of specific problems:

1. Initially there is the *Research* that can be done to relate weather to gas deliveries on a long-term basis. A study of this kind may resolve itself into a series of graphs which can be used for forecasting gas deliveries in future years, whether by months or seasons. Delivery data described in this instance are representative of the quantity of gas used by residential consumers, principally for space heating, and

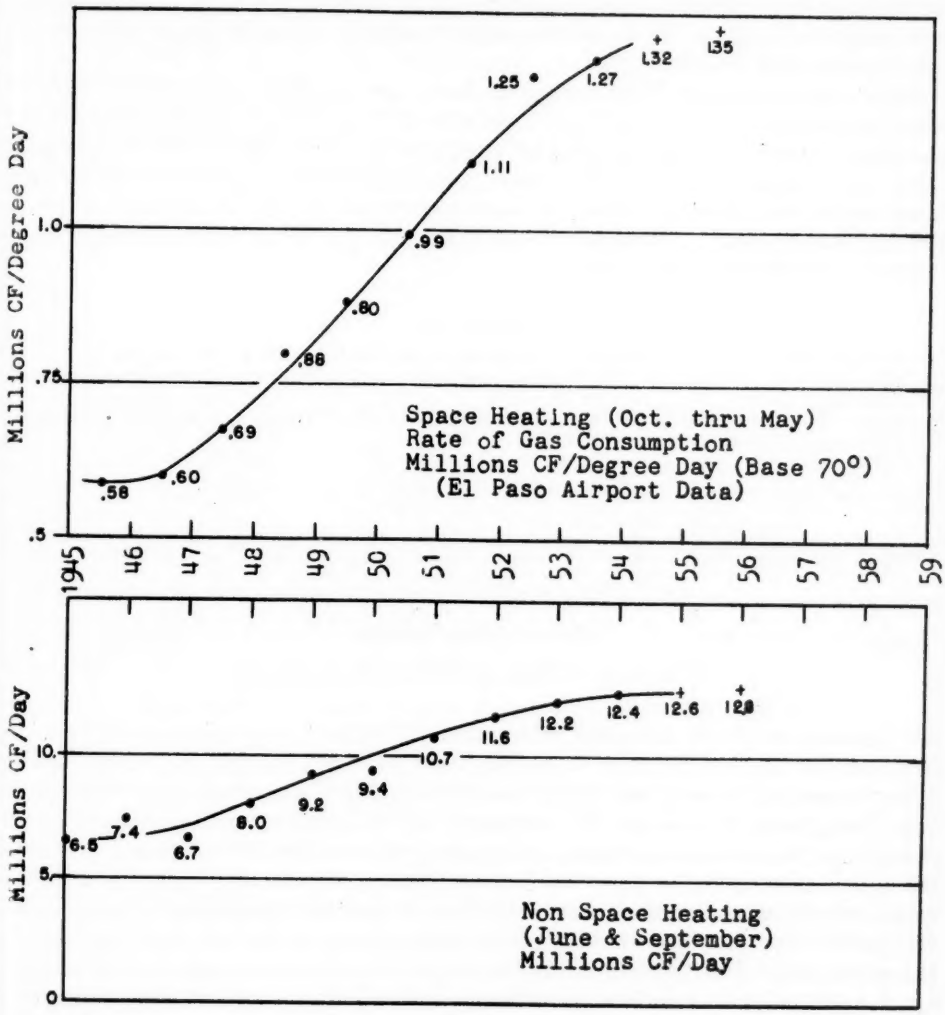


Fig. 1.

small industrial users, such as hotels and laundries. Gas used by large industrial firms and power companies is not included, since those values are roughly consistent (Fig. 1).

Calculations for the case discussed were based on the assumption that some heating is required in the El Paso area on any day when the average temperature is less than 70°F. This is 5° warmer than the base of 65°F. more commonly used.

Research processes and forecast techniques involving the manipulation of large quantities of data have been given tremendous impetus in the last few years by the increasing use of sorting and calculating equipment. Problems hitherto unsolved,

by reason of the vast amount of human effort necessary, are now being tackled and resolved by machine techniques. By these methods, too, human fallibility on the part of forecasters is being substantially reduced.

2. Next there are the *Climatological Studies* based on hourly data which serve as useful pre-planning guides for operations that are at present outside the time-span of any forecasting technique in current use. The pipeline constructions survey is a case in point.

3. *Longer-range Forecasts.* When the operation comes within forecast range, the average or probability figures given in the climatic review can be translated into 'expected' values—be it for a month or season—from the anomaly maps of precipitation and temperature.

Short-range Forecasts. Short-range forecasts are especially important if load is likely to be critically high, or low. Forecasts of temperature, precipitation, wind direction, cloud cover, the presence of hurricanes or snow and ice, are needed on a short-term warning basis of a few hours, as well as for the next twenty-four- and forty-eight-hour periods, and for the next seven days. In fact, the dispatcher needs weather information in as much detail as he can get it for every possible time interval—whether long or short.

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THE ESTIMATION OF WATER NEED AND THE WATER BUDGET IN ENGLAND AND WALES

By G. Melvyn Howe

(*University College of Wales, Aberystwyth*)

An assessment of the adequacy of rainfall to support vegetation or to provide surpluses for the maintenance of ground-water supplies, the flow of streams or the filling of reservoirs must take into account losses due to evaporation and transpiration. Evapotranspiration can be measured but it is influenced by many factors peculiar to the observation site in both space and time. Increasing attention is now being paid to *potential* evapotranspiration. This is defined as the quantity of water which would transpire and evaporate from a surface completely covered with vegetation under conditions of sufficient water supply in the root zone of the soil. It has been argued that differences in the vegetation cover from one place to another, e.g. as between grass and dense woodland, vitally alter the potential evapotranspiration rate. But several recent papers (1) have demonstrated that under conditions of *adequate* water supply (i.e. when *actual* evapotranspiration over a watered area is equal to the *potential* evapotranspiration) this is a misconception and that the degree of variation due to this cause is relatively very small.

Potential evapotranspiration, or more simply, water need, can be measured by means of an apparatus similar in essentials to that described by Garnier and Lewis (2). Briefly it consists of a large soil tank in the ground which is so constructed that plants can be grown in it under essentially field conditions and can be provided with water as they need it. A known quantity of water is sprinkled on to the soil surface daily to maintain an adequate supply and any natural precipitation is also measured. Any water that drains through the soil is collected and led off to a

measuring cylinder. Water need is thus the only unknown in the water-use equation and is obtained by summing up the precipitation and the amount of water applied artificially and subtracting the amount collected in the overflow.

Unfortunately such measurements of potential evapotranspiration are scanty in this country and recourse has to be made to empirical formulae for calculating this climatic factor. Applying the formula devised by C. W. Thornthwaite (3) to climatic data for 112 stations in England and Wales, average annual water need has been computed for each and their respective moisture balances determined. The results have been plotted and maps have been prepared to show the geographical distribution in England and Wales of (*a*) average annual water need (potential evapotranspiration), (*b*) seasonal water surplus, (*c*) seasonal water deficiency, and (*d*) moisture regions, based on a series of hygrostatic indices. These maps (which are preliminary and subject to revision) have been published and described elsewhere (4), but three graphs comparing the seasonal trend of water need, precipitation and water storage at Sheffield, Aberystwyth and Southend are given in Fig. 1.

In the case of *Sheffield*, annual average precipitation amounts to 31 · 1 in., whereas annual average water need is computed at 24 · 5 in. From late November until late

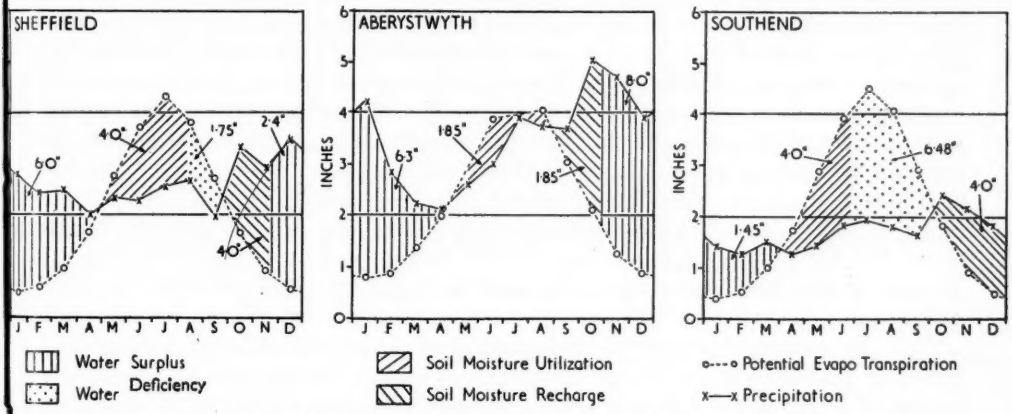

Fig. 1.—Annual variation of water need and precipitation at Sheffield, Aberystwyth and Southend.

April there is a period of full storage when precipitation exceeds water need and a moisture surplus amounting to 8 · 4 in. accumulates, of which 4 in. is assumed to be stored in the soil and available for later use by vegetation. From late April until late September there is a drying season when stored moisture and precipitation are used in evapotranspiration. Storage is steadily diminished until moisture deficiency of about 1 · 8 in. occurs on an average between early August and late September. The period late September to late November is a moistening season when precipitation again exceeds water need and soil moisture is recharged.

At *Aberystwyth*, water need rises rapidly in the spring from less than 1 in. during the winter months to 4 in. in August, and then falls quite as rapidly again in the autumn. Total average annual water need is computed at 27 · 8 in. and the annual precipitation is 41 · 8 in. Current rainfall is less than need from about the middle of May to late August, but the difference is made up from water storage in the soil. From the end of August the rainfall not immediately needed goes to replace stored soil moisture that has been used up and it is not until the middle of October that the soil moisture has been completely recharged. There is then a surplus which raises ground-water levels and produces surface and sub-surface run-off, but it is of no benefit to plants. Between late October and early May there is a total surplus of about 14 · 3 in.

At *Southend*, water need follows the same pattern as that for Sheffield and Aberystwyth except that the average annual rainfall is here only 20·5 in. and water need is computed at 25·6 in. For the six months April–September inclusive water need exceeds rainfall. From mid-March to late June demands for water are satisfied from soil moisture reserves. By July these reserves are exhausted and vegetation has to rely solely on current rainfall. But current rainfall is not enough. Water supply falls below water need to the extent of 6·5 in. for the period late June to mid-September; presumably plants suffer and growth is retarded in an average year. It is not until October that rainfall again exceeds need, but it would appear that complete recharge of soil moisture is not achieved until mid-January, after which and until mid-March there is a small water surplus of about 1·5 in. That complete recharge of soil moisture does not take place until mid-January is an interesting conclusion for observed conditions at the end of the summer dry spell would suggest otherwise. However, the unexpectedly quick resumption of high flow rates in the rivers may be due partly to the quick or 'flash' run-off of a certain amount of precipitation which escapes absorption in the soil.

Graphs such as those for Sheffield, Aberystwyth and Southend offer a method of estimating probable irrigation requirements, though conclusions based on long-term averages tell only a partial story. Ideally the water need in individual years should be compared with water supply by a system of monthly water book-keeping whereby it becomes possible to determine the amount of water that is required to maintain optimum soil-moisture conditions. The difference between the graph of water need and the graph of rainfall, assuming that the former is the greater, is a measure of the irrigation water required to attain optimum content of soil moisture, one inch of irrigation water being the equivalent of about 22,500 gallons per acre. Thus, in the case of Sheffield in an average year, about 24,750 gallons in May, about 108,500 gallons in June, about 210,000 gallons in July and 225,000 gallons in August should be applied to every acre to maintain optimum content of soil moisture.

The Thornthwaite approach and method of using climatological statistics to arrive at a knowledge of the real factors in climate, though not perfected, does represent a valuable contribution to climatological research and is of undoubted service to man. The hydrologist can use the map of water surplus to gain an approximate knowledge of average run-off where no actual measurement is made, while the method of computing current water surplus for a given season from meteorological data alone is a useful starting-point in predicting available run-off. Plant breeders have always been hindered in their work by the lack of fundamental climatic data and quantitatively defined climatic regions. The maps of water need (i.e. potential evapotranspiration) and water deficiency for England and Wales partially fill this gap. The map of moisture regions indicates homoclimes for the benefit of scientists engaged in plant introduction work. The plant pathologist could gain a clearer knowledge of the climate advantageous to insect pests and disease organisms through a correlation of the times of infestation and the life cycle of the pathogen with related water surplus and deficiency, while the pedologist is well aware of the important role played by water surplus and water deficiency in the development of the soil.

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RAINFALL STUDIES AND WATER SUPPLY PROBLEMS IN THE BRITISH ISLES

By S. Gregory
(*University of Liverpool*)

In the past few years much attention has been paid to the problem of providing adequate water supplies in Britain, especially in relation to increased demand. This itself results from increases and changes in population, industry, power generation and agricultural practice. Moreover, there is also the need to increase reserves to guard against any decrease in incoming supplies as the result of a period of low rainfall. Whether or not these problems are solved is as much an economic as an engineering question, for the 'striking of the balance between over-insurance and under-insurance is seldom easy, and heavy over-insurance would mean that the consumer would pay more than he should' (1). It is in helping to strike this balance that rainfall studies make their major contribution.

The basic minimum information which is required is a series of large-scale maps of monthly and annual average and relative variability values, all calculated for the same recent period. The only large-scale map at present available is of mean annual rainfall for 1881–1915 (2), whilst there are also small-scale maps of average monthly and annual falls for 1901–30 (3). Only the annual values of relative variability have been recalculated for this period (4), and the contrast between these and 1881–1915 conditions (5) suggests that the monthly maps should be redrawn too. It is to be hoped that the 1916–50 values, when their verification and calculation have been completed by the Meteorological Office, will be published in map, as well as tabular, form.

Rainfall regime is also important, and isomeric maps (6) showing the percentage of the year's average fall which occurs in any specific month, stress the winter concentration of precipitation in north-western areas and its summer concentration in Eastern England. By the use of different techniques regional limits can be set to the various regimes (7) and a broad distinction drawn between areas with, and areas without, a marked winter maximum. Only the East Anglian region shows any marked summer maximum, however, and this is an area where total fall is low and summer evaporation high (8). A summer water surplus does not therefore result, and, with the absence of any real summer maximum elsewhere, this stresses the importance of winter replenishment in the overall water budget of the country.

In any given year, however, this seasonal regime may not occur. Studies of exceptions and extremes are therefore very valuable (9), especially to indicate the magnitude of the possible deficit, but a statistical assessment of the frequency with which specific critical conditions are liable to occur, comparable to that for East Africa (10), has yet to be made. The full significance of any individual extreme occurrence is partially controlled by the conditions of the preceding and succeeding periods, so that a study of the long-term trend of rainfall is very necessary. For annual conditions at least, considered on the basis of ten-year running means for 1881–1950, marked differences in trend are evident, and these fall into a distinct regional pattern (11). The extreme range between decadal means is often quite considerable, being up to 25–30 per cent, and in most areas the 1880's and 1890's were markedly drier than the 1920's and 1930's. These conditions of more frequent dry years are likely to recur, with the result that any estimate of water resources based on twentieth-century rainfall values may well prove falsely optimistic.

Despite these and many other studies, there is still scope for further research along established lines, but concentrating far more than hitherto on monthly and seasonal conditions. There is also the need for rainfall studies specifically directed

towards helping to solve particular water supply problems. To this end, a distinction must be drawn between surface supplies (from impounding reservoirs, upland gathering grounds and springs), underground supplies and water drawn from rivers. Each of these three major types of source requires different rainfall information, and each will react differently to the same set of rainfall conditions. For surface water the methods outlined earlier will provide full data on incoming supply for any existing or proposed catchment area. Actual yield, however, will also depend on evaporation losses, storage capacity and rate of run-off, this latter itself being governed by the lithology, physiography, vegetation and actual size of the catchment area. These factors can either accentuate or minimise the rate at which water is being made available by rainfall. Yet a further limitation upon yield is the statutory requirement for the release of compensation water to maintain stream flow in the lower reaches. Unfortunately this value is usually unrelated both to the peculiar nature of the individual drainage basin and to the present-day economic activity within it. For river supplies the same considerations hold true, save that the environments to be considered are both more numerous and more varied. The existing rainfall studies are probably of less direct value for underground supplies, for the catchment areas for such sources, resulting from geological structure, are normally restricted in size and frequently not accurately known. In all these cases, however, it is clearly necessary not merely to study rainfall, but also to relate it to the complex character of the surface upon which it falls.

The utilisation of the various types of water source does not always occur in any definite regional pattern. Neighbouring water authorities, and even one authority, often obtain water from different types of source, and these local variations are clearly seen in Lancashire[1] (Fig. 1*a*). In general the hill areas rely upon reservoirs and other upland sources, whilst in the lowlands, especially upon the sandstones of South-western Lancashire, underground sources are used except in the case of such conurbations as Liverpool and Manchester which get their water from afar. The type of rainfall information required, and the value of the existing studies, thus varies considerably within this one county.

The broad distinction between reservoirs for uplands and cities, and underground supplies for lowlands, does not invariably hold true. This is largely because of the major role assumed by Liverpool and Manchester as suppliers of water in bulk to numerous other authorities, both within Lancashire and in neighbouring counties (Fig. 1*b*). These two cities also help to serve other areas indirectly; for example, although Darwen buys water in bulk from Bolton, the latter itself receives part of its supplies from Manchester. Therefore, from five relatively limited upland areas (Thirlmere and Haweswater in the Lake District, Longdendale and Rivington in the Pennines, and Lake Vyrnwy in Wales) much of North-western England and parts of Wales draw all or part of their water. This would seem to be a sensible and efficient use of the incoming supply. In fact, along with Birkenhead's Alwen Reservoir scheme and several other more limited bulk supply arrangements in Lancashire, this could form the basis of a regional water grid. By capitalising on the most favourable sites, this could provide water as economically as possible, and it is in the selection of such future development sites that rainfall studies must play their part.

The need for such integrated schemes is stressed by the fact that demand is increasing even faster than was estimated a few years ago. In 1947/8 the average daily consumption in Lancashire was almost 240 million gallons, and the planning estimate made then for 1957 was just under 295 million gallons, an increase of some 56 million gallons in twenty-seven years. By 1955, only seven years after this estimate, consumption was already 29 million gallons per day above the 1947/8

[1] For much of the information on Lancashire, both in the maps and the text, I am indebted to the County Planning Department, Preston.

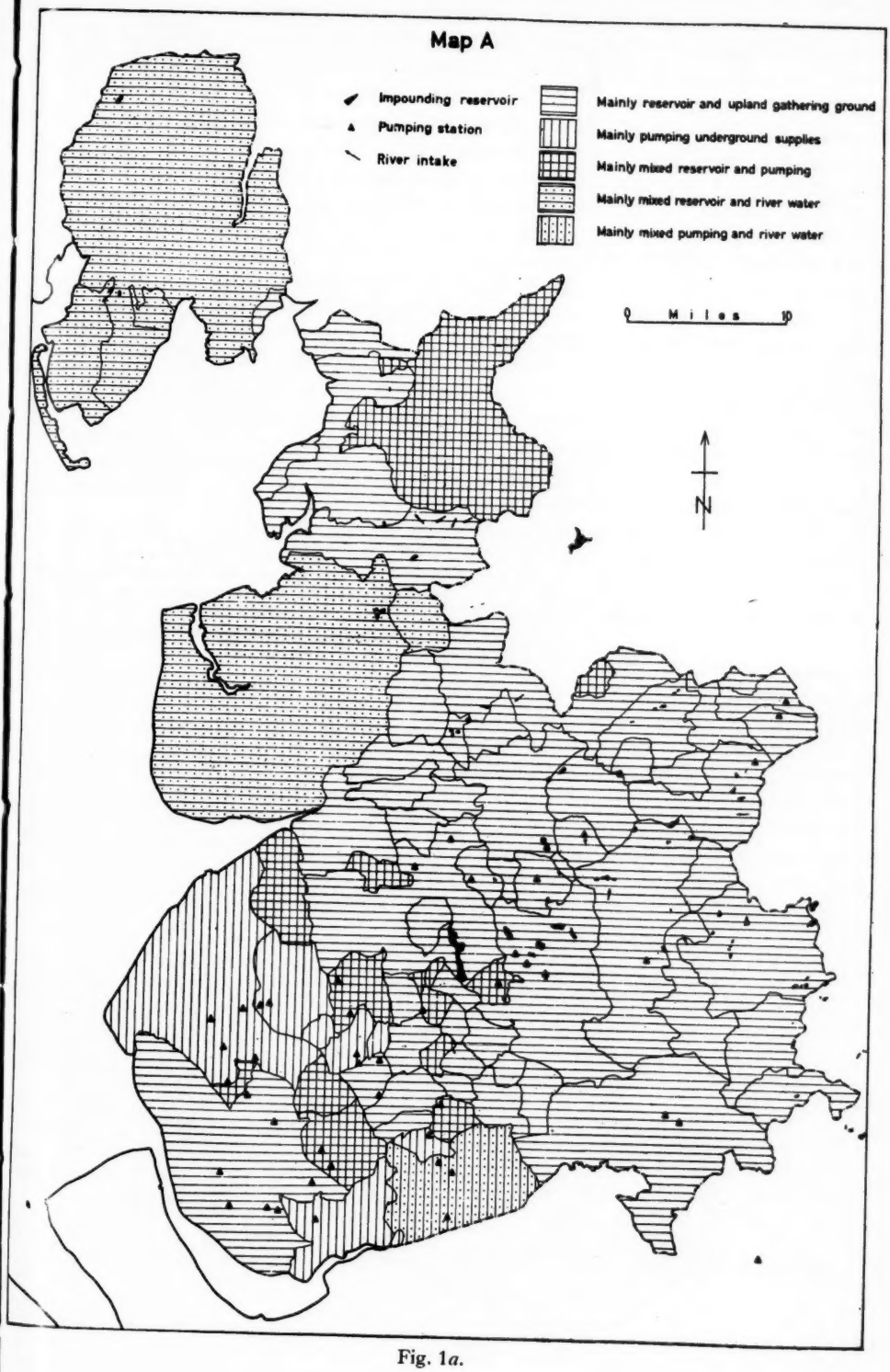
Map A
Impounding reservoir
Pumping station
River intake
Mainly reservoir and upland gathering ground
Mainly pumping underground supplies
Mainly mixed reservoir and pumping
Mainly mixed reservoir and river water
Mainly mixed pumping and river water
0 Miles 10
N

Fig. 1*a*.

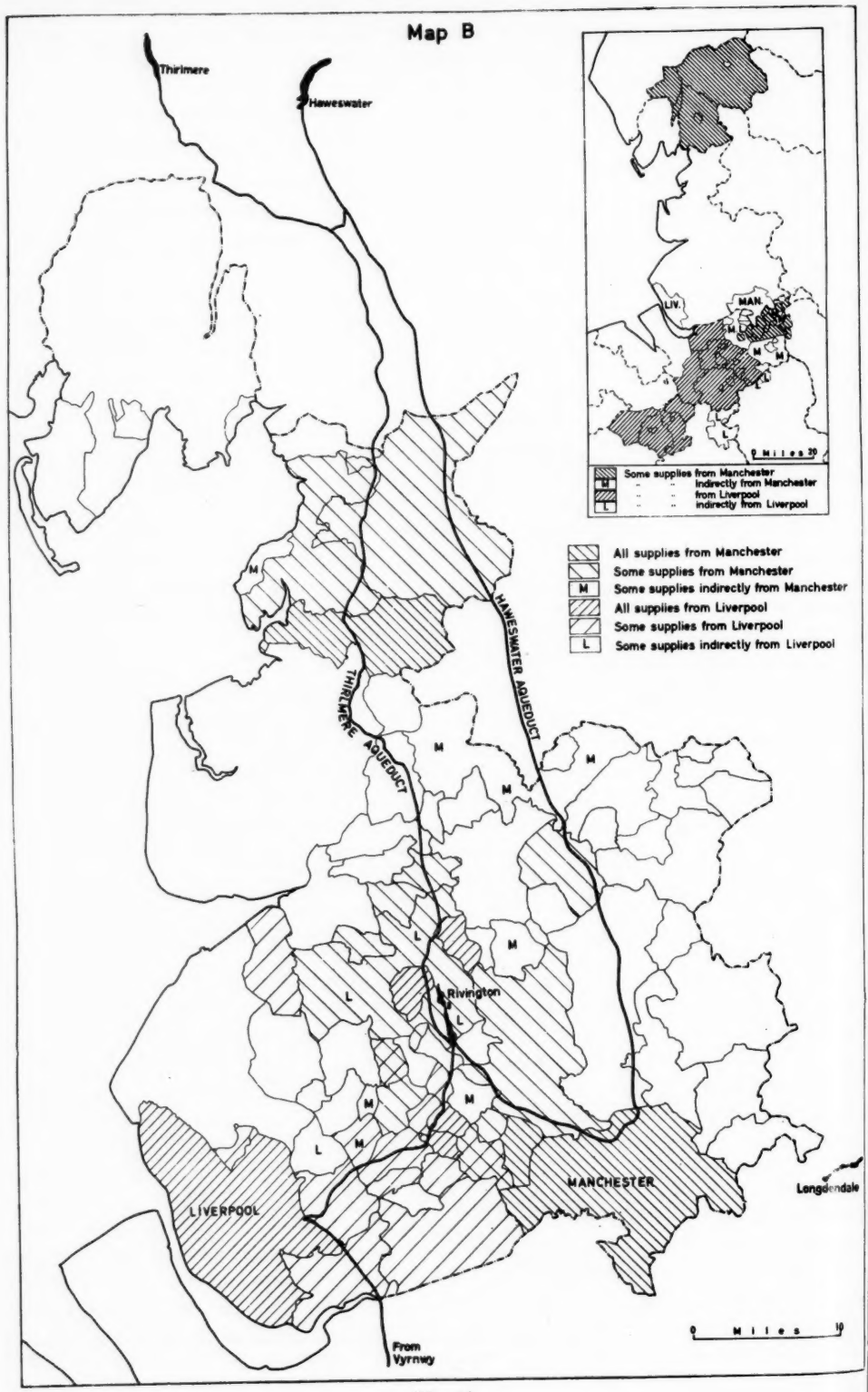
Map B
Thirlmere
Haweswater
HAWESWATER AQUEDUCT
THIRLMERE AQUEDUCT
Rivington
MANCHESTER
LIVERPOOL
Longdendale
From Vyrnwy
0 Miles 10
All supplies from Manchester
Some supplies from Manchester
Some supplies indirectly from Manchester
All supplies from Liverpool
Some supplies from Liverpool
Some supplies indirectly from Liverpool
LIV.
MAN.
0 Miles 20
Some supplies from Manchester
Indirectly from Manchester
from Liverpool
indirectly from Liverpool

Fig. 1*b*.

level, for many authorities have almost reached their estimated 1975 requirements and a few have in fact exceeded them. Moreover, as the measure of available untapped supplies for future use, it is completely misleading to take the difference between the total fall of rain and the amount of water already supplied, even if due allowance is made for evaporation losses and compensation water. In Lancashire most potential reservoir sites are in fact already used (Fig. 1*a*), whilst many of the remaining upland valleys contain either considerable built-up areas or major lines of communication, or else their value is limited by geological or physiographical conditions. Thus it is only by considering the actual limited exploitable areas that a more valid estimate of potential water resources via reservoirs may be made. For large projects the present tendency is to look beyond the county boundary to the Lake District, as with Manchester's Swindale Valley plan, or to North Wales, as with Liverpool's Tryweryn Valley scheme.

Many of these difficulties do not apply to the abstraction of river water, which can thus provide a means of utilising rain which falls over, or drains through, valleys unsuitable for reservoir construction. On the other hand, irregularity of flow is a major problem, whilst pollution of river water in urban areas frequently prevents its use for domestic consumption. The other alternative is to increase pumping of underground reserves, including water from coal-mines, much of which is readily usable at least for industrial purposes. However, before any large-scale pumping could become a legitimate and continuous source of increased supply, further study is required of the area drawn upon by each pump, and of the incoming supply of rainfall which must replenish its reserves. Otherwise it could well be that the present numerous pumping stations (Fig. 1*a*) would themselves suffer as a result of careless expansion.

It would seem, therefore, that further studies of rainfall and its influence on water supplies are still required. These studies, however, should be directed and controlled by a realisation of the nature of the problems presented by the various types of water source, and the variation in the significance of different sources between one area and another. This attempt to relate rainfall to the overall character of the area upon which it falls implies the consideration not merely of atmospheric processes but also of geological structure and lithology; physiography, soils and vegetation; settlement, industry and administration; and the planned future development of the area. In this field of relating climatic phenomena to the landscape, the geographical climatologist can make a valuable contribution.

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THE CLIMATIC ASPECTS OF IRRIGATION DEVELOPMENT IN NIGERIA

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In considering the climatic aspect of irrigation development in Nigeria it is necessary to concentrate mainly upon moisture conditions since the country's

tropical location means that temperatures are suited to the growth of crops throughout the year. The mean annual rainfall is over twenty inches everywhere, and exceeds sixty inches south of latitude 7°N. The total is, however, unevenly spread through the year since the country experiences well-marked wet and dry seasons. The duration of the latter increases away from the coast. Thus, whereas between 50 per cent and 60 per cent of the mean annual rainfall comes during June, July, August, and September in the south, the proportion falling in these four months rises to 90 per cent or higher north of the central plateau. To this seasonality must be added a high percentage variability during individual months, especially during those at the beginning and end of the rains. At Ibadan, for example, the mean percentage variability in March is 58 per cent, and at Kano, in May, it is 53 per cent.

The irregularity of rainfall incidence suggested by these figures is further emphasised by considering the daily incidence of rainfall and the nature of individual falls. In Nigeria the rain arrives characteristically in heavy showers of short duration. The initial rate of fall is often three inches an hour or more, but such intensity rarely lasts more than half an hour. Thereafter there is a steady downpour which tails off into a drizzle. The result is that a large proportion of each month's rain comes in a relatively short time, as Table 1 shows. An analysis of the rainfall charts

TABLE 1

(a) *Some Rainfalls at Ibadan*

Date	Amount (mm.)	Duration (min.)	Percentage of month's total
26 July, 1953	11	50	9
21 March, 1954	81	360	33
3 October, 1955	15	30	7
26 November, 1955	20	50	32

(b) *Monthly Rainfall at Samaru* (*Zaria*), *May–September*, 1953

Month	Amount (mm.)	No. of falls	Comments
May	255	16	65 % of total in 4 falls
June	151	13	80 % ,, ,, ,, 4 ,,
July	294	13	85 % ,, ,, ,, 5 ,,
August	197	17	75 % ,, ,, ,, 5 ,,
September	227	18	60 % ,, ,, ,, 4 ,,

for Ibadan from 1952 to 1955 suggests that in individual falls of rain producing over half an inch over 85 per cent of the rain comes during the first thirty minutes of the storm, the average duration of which is two hours or more.

A further aspect of Nigeria's climate which vitally affects irrigation is the high rate of potential evapotranspiration (Fig. 1).[1] This exceeds 1000 mm. a year practically everywhere, and north of the Niger-Benue trough the figure rises above

[1] B. J. GARNIER: 'Report on experiments to measure potential evapotranspiration in Nigeria', *Univ. Coll. Ibadan, Res. Notes*, No. 8, January 1956.

1600 mm. except on the cooler region of the Jos plateau. These annual totals arise from daily values which vary from 3 mm. to 5 mm. or more according to the season. When they are examined in conjunction with the arrival of precipitation two facts emerge. The first is that because of the seasonal incidence of rainfall every part of the country has a period of water deficiency, varying from a few weeks in the south to several months in the north, and a period of water surplus during which run-off is considerable in the south but small in the north. The second fact is that, having

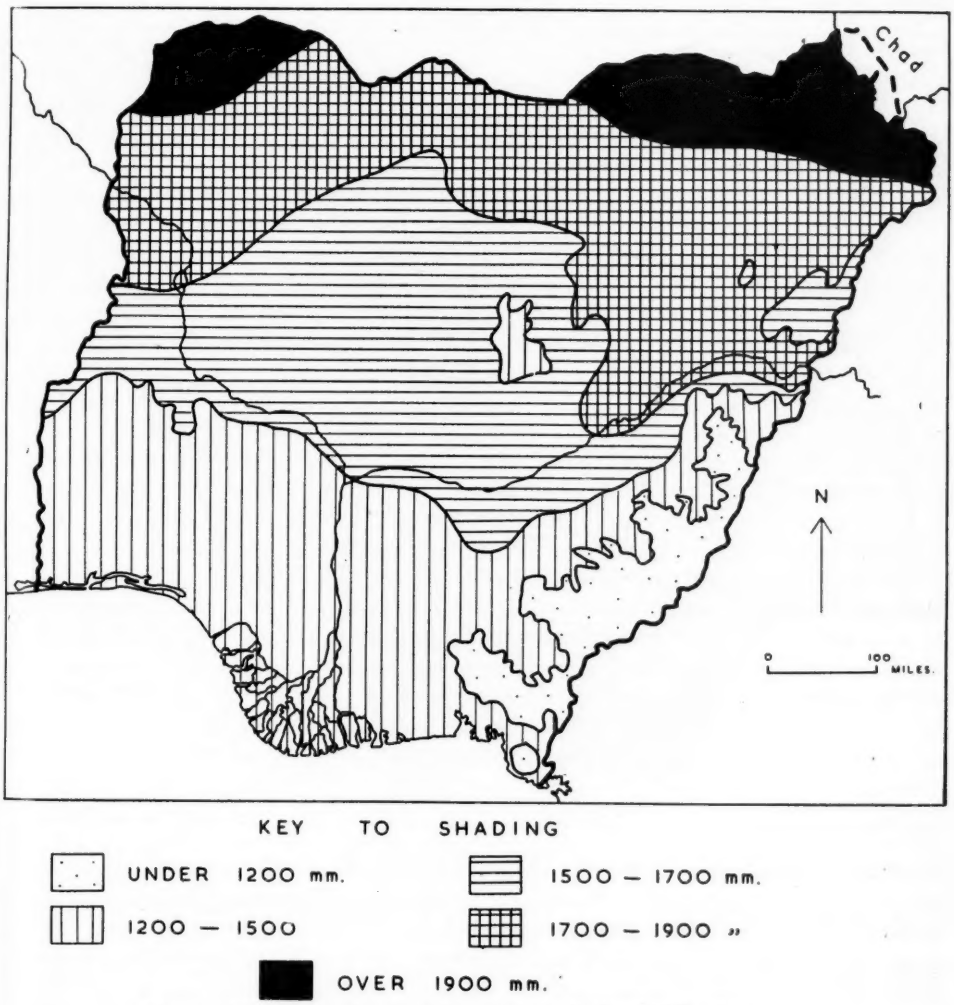

Fig. 1.—Mean Annual potential evapotranspiration in Nigeria.

regard for the irregular daily incidence of rainfall, days of water deficit may be widely expected even at the height of the rainy season.

The results of the foregoing considerations are summarised in Fig. 2. Southern Nigeria is a region where water surplus greatly exceeds water deficit. Here, in view of the long duration of the humid season (defined as the period when mean rainfall exceeds or equals mean potential evapotranspiration), what irrigation is needed may be satisfactorily obtained by using wells, or perennial streams, and by developing small, local schemes. North of the Jos plateau, however, the picture is one of considerable water shortage. The surplus available as run-off is too little to encourage large-scale irrigation development. Agriculture here is localised and

depends heavily upon underground water supplies. There is, finally, a broad middle belt of Nigeria where the climatic analysis suggests the possibility of modern irrigation development. The many streams flowing into the Niger and the Benue from both sides, and the streams of the Ogun river catchment, all tap areas of good water surplus. This region, moreover, is scantily peopled at the moment, and it is here that pilot schemes may perhaps be most usefully undertaken to see what the chances are of developing crops and pastures under irrigation for the creation of the mixed farming which Nigeria so badly needs.

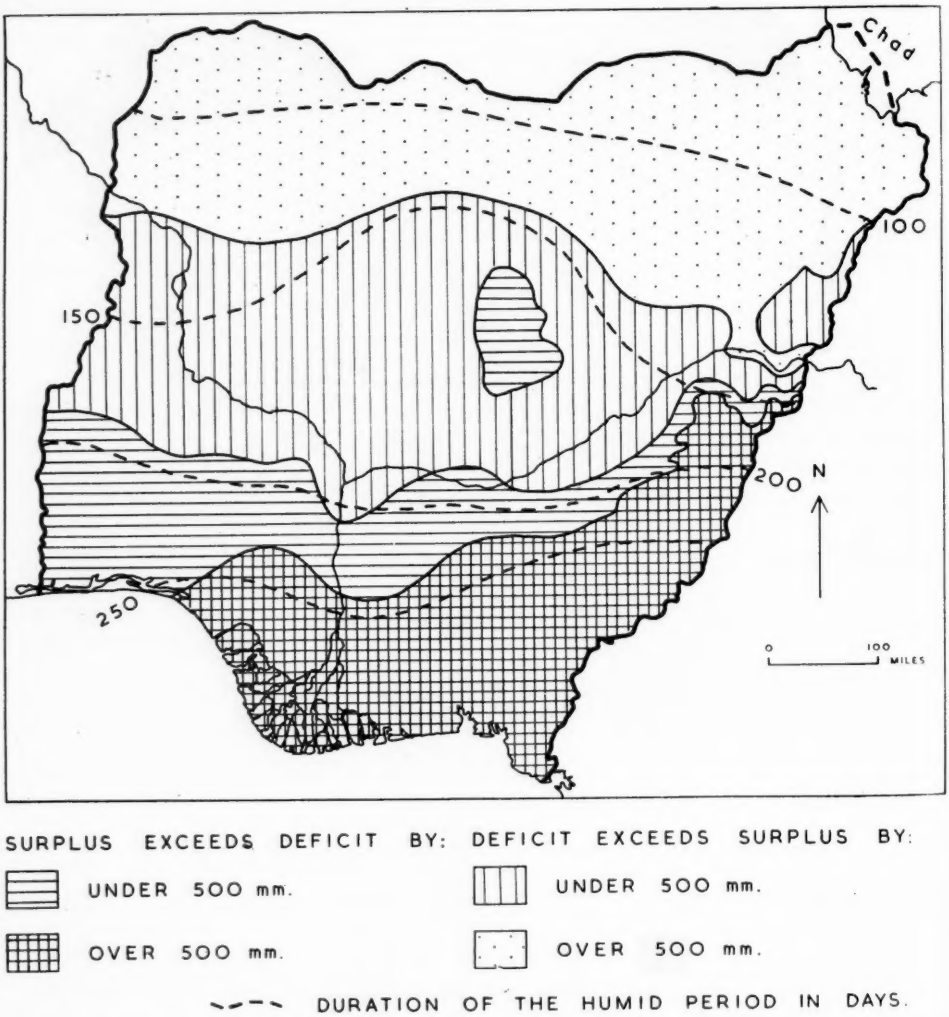

Fig. 2.—Relationship of Mean Annual Water Surplus to Mean Annual Water Deficiency in Nigeria.

THE CLIMATIC APPROACH TO POTENTIAL EVAPOTRANSPIRATION

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The loss of water by evaporation and transpiration from a permanently moist surface is controlled primarily by the climatic conditions. The problem of expressing this potential rate of moisture loss in terms of climatic data appears to be one of

some importance to climatologists and agriculturists because of the scarcity of experimental results and the uncertainty which attaches to some of these. Both empirical and theoretical lines of approach have been pursued.

The empirical methods fall broadly under two headings. Under the first may be placed attempts to capitalise on the relationship which exists between evaporation and the moisture content of the air near the surface. In such treatments the rate of evaporation is regarded as a function of the saturation deficit of air. This method fails because the saturation deficit is related to the moisture content at a single point in space while the rate of evaporation is governed by the vertical distribution of water vapour above the evaporating surface. The relationship between evaporation and saturation deficit must therefore vary according to the nature of the water vapour stratification in the air layers immediately above the surface.

Thornthwaite (1948), on the other hand, has sought to express potential evapotranspiration as a function of the mean temperature and the duration of daylight, two quantities which, unlike the moisture content of the air, are quite independent of the rate of evaporation. His method is indeed applicable over a wide range of climatic conditions; ultimately, however, it fails because it proves unable to differentiate between all the combinations of thermal and hygrometric regimes which are experienced. In particular it can be shown that Thornthwaite's formula breaks down numerically because of structural considerations in hot, dry climates, in which it consistently underestimates the potential moisture loss, and in polar regions where the summer estimates prove unduly high. For instance, at a hypothetical Antarctic station at which the mean temperature rises to 32·4°F. in December and remains below freezing-point during the remainder of the year, the computed potential evapotranspiration would amount to 13·7 in. in December and be nil in the remaining months, a result which clearly is absurd.

The determination of potential moisture loss can be approached theoretically from two distinct aspects. The first method seeks to establish the rate at which water vapour is diffused away from the surface. The second line of approach consists in determining the amount of energy utilised in evaporation. Both methods in their original form require a knowledge of the surface temperature which is rarely available. Penman (1948) was able to eliminate this requirement by combining the two treatments. His method, which has been applied with success to a variety of agricultural problems, is the most soundly based and accurate of those so far devised to solve the problem of potential moisture loss. Certain aspects of Penman's formulation however would seem to require modification in the light of recent research. In particular the empirical treatment adopted by Penman for the diffusion aspect of the problem is slightly at variance with the theoretical form derived by Sir Graham Sutton (1949*a*, 1949*b*) and neglects the dependence of evaporation on the geometrical roughness of the surface. An elaboration of the relationship between incident radiation and the duration of sunshine also appears desirable.

An attempt has been made, on the basis of these developments, to extend the method evolved by Penman by combining a slightly elaborated form of the energy-balance equation with Sir Graham Sutton's theoretical vapour transfer equation.[1] The results obtained lead to the following general conclusions:

(1) In the combined equation the incident radiation is usually the dominant factor.

(2) Two factors differentiate between surfaces of different kinds. These are (*a*) the roughness and (*b*) the albedo, which express the aerodynamic and energetic properties of the surface respectively. Potential evapotranspiration and evaporation from a free water surface are therefore closely related.

(3) The rate of potential evapotranspiration decreases as the dimensions of the moist surface increase, but the change becomes negligible when the radius exceeds

[1] A detailed account of this work is in course of preparation.

approximately forty feet. This result emphasises the need to maintain an abundant supply of moisture in the area immediately surrounding an evapotranspirometer when an estimate of the potential moisture loss from a large irrigated area is required.

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